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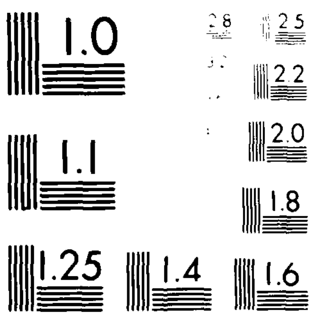

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GRAND FORKS - EAST GRAND FORKS URBAN WATER RESOURCES STUDY

WATER SUPPLY APPENDIX

CORPS OF ENGINEERS
ST. PAUL DISTRICT
JULY 1981

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER	2. GOVT ACCESSION NO. AD-A110270	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) GRAND FORKS-EAST GRAND FORKS URBAN WATER RESOURCES STUDY; Water Supply Appendix		5. TYPE OF REPORT & PERIOD COVERED Final; 1978-1980
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s)		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Stanley Consultants, Inc.		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS ARMY CORPS OF ENGINEERS, ST. PAUL DISTRICT 1135 USPO & Custom House St. Paul, Minnesota 55101		12. REPORT DATE July 1981
		13. NUMBER OF PAGES 212 p.
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassifed
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

This report is one of ten

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Urban planning
Water supply

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The St. Paul Corps of Engineers conducted the Grand Forks-East Grand Forks Urban Water Resources Study in a cooperative effort among local, state and federal agencies. This appendix consists of three reports: Water Supply Study- Problem Identification/Alternative Formulation/Evaluation; Water Supply Study Final Report (1980); and Low-flow Frequency Analysis of the Red River of the North at Grand Forks and Red Lake River at East Grand Forks.

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A low-flow study of drought flows on the Red and Red Lake Rivers found that river flow, plus storage provided by the cities' low-head dams, would satisfy 2030 demands during a 50-year drought. The uncertain future of the Garrison Diversion Unit made it an unsatisfactory alternative water source. The Elk Valley and Beach Ridge aquifers were unsuitable because of inadequate recharge rates. The most economical treatment and supply alternative would be for the two cities to develop a combined system in 2005. A water conservation program was proposed which could reduce demand and costs. A five-stage drought emergency plan of action was developed to cope with drought conditions more severe than the 50-year design event.

PREFACE

The Corps of Engineers' Urban Study Program is aimed at providing planning assistance to local interests in a variety of water and related land resource areas, including water supply, wastewater management, flood control, navigation, shoreline erosion, and recreation. In areas of traditional Corps responsibility (such as flood control), the Corps may implement and construct projects shown feasible in the urban study. In other areas (such as wastewater management), Corps involvement carries only through the planning stage; findings are turned over to local interests for incorporation into their broad urban comprehensive planning report. Implementation is at the discretion of local interests in conjunction with appropriate State and Federal agencies.

The St. Paul District, Corps of Engineers, conducted the Grand Forks-East Grand Forks (GF/EGF) Urban Water Resources Study, which was a cooperative effort among local, State, and Federal agencies. The GF/EGF urban study spawned a time of transition in the Corps' urban study program. In mid-1978, directives were issued deleting the third and last stage of urban studies. At that time, the second stage of the GF/EGF urban study was nearing completion, and commitments for stage 3 studies had been made to local interests and involved State and Federal agencies. Therefore the GF/EGF urban study was allowed to proceed to stage 3.

During the first stage, the 14-township study area was selected, broad topical problems to be addressed (water supply, wastewater management, and flood control) were identified, and a "plan of study" was developed. The plan of study outlined the general approach the study would follow. During stage 2, the topical problems were broken down into explicit problem areas. Investigators formulated a broad array of alternatives to resolve the study area's problems. The alternatives were evaluated to eliminate those which were not suitable or cost effective. The stage 3 study examined in detail those alternatives that passed the stage 2 screening. Alternatives were reassessed to determine their respective cost effectiveness and environmental/social impacts.

This particular document is 1 of 11 constituting the GF/EGF urban study report:

Summary Report
Background Information Appendix
Plan Formulation Appendix
Water Supply Appendix
Wastewater Management Appendix
Flood Control and Urban Drainage Appendix
Flood Emergency Plan for Grand Forks, North Dakota
City of East Grand Forks, Minnesota, Civil Defense Flood Fight Plan
Energy Conservation and Recreation Appendix
Public Involvement Appendix
Comments Appendix

This appendix consists of three reports prepared by Stanley Consultants, Incorporated, under contract to the St. Paul District, Corps of Engineers:

1. Stage 2 Water Supply Study - Problem Identification/Alternative Formulation/Evaluation (September 1978) provides an initial screening of alternative water sources and treatment/delivery systems.

2. Stage 3 Water Supply Study Final Report (March 1980) presents more detailed analyses of promising alternatives.

3. Stage 3 Low-Flow Frequency Analysis of the Red River of the North at Grand Forks and the Red Lake River at East Grand Forks (September 1979) provides drought analyses of these rivers.

These three reports are included to provide the reader with a complete sequential picture of the planning effort during the urban study. While reading these reports, the reader may encounter repetitious or apparently contradictory materials. Such cases reflect the iterative analytical process which relied on an evolving data bank.

The stage 2 study eliminated several proposed water sources and treatment/delivery systems. It determined, for instance, that the Dakota aquifer and wastewater lagoons were not suitable sources and that a single water supply system serving the entire study area was not cost effective.

The stage 3 low-flow study analyzed the severity and frequency of drought flows on the Red and Red Lake Rivers in relation to projected 2030 water withdrawals. It was found that river flow, supplemented by existing in-channel storage provided by the cities' low-head dams, would be sufficient to satisfy 2030 demands during a 50-year drought.

The stage 3 water supply study evaluated other water sources, including the Garrison Diversion Project and Elk Valley and Beach Ridge aquifers. The uncertain future of the Garrison Project made it an unsatisfactory alternative. The aquifers were unsuitable because of inadequate recharge rates.

The stage 3 study also assessed a variety of treatment and supply systems combining:

- Two levels of treatment.

- Two schemes for combining the cities' water treatment works and one scheme for separate systems.

- With and without water conservation measures.

The study concluded that the most economical alternative, regardless of level of treatment, would be for the two cities to develop a combined water treatment and supply system in 2005.

The study found water conservation measures could reduce demand up to 10 percent. Conservation measures include public education programs, changes in building codes to require water saving fixtures, retrofit of water saving devices on toilets and showers, reduction of municipal

and industrial losses and waste, and changes in the water rate structure. A five-stage drought emergency plan of action was developed to cope with drought conditions more severe than the 50-year design event. The initial stages of this plan rely on voluntary measures to reduce water demand; later stages impose mandatory restrictions that could reduce demand by more than 60 percent.

Because Corps involvement in the water supply topic only carried through the planning stage, the Corps was not required to prepare an environmental impact statement. Therefore, the impact assessment discussion in this appendix should not be considered a definitive or final environmental/social impact evaluation of the alternatives and recommended plans. The discussion, however, does indicate areas of special concern that may require further study. Agencies involved in implementing any of the alternatives should comply with applicable requirements of the National Environmental Policy Act of 1969 (Public Law 91-190) and subsequent legislation.

The St. Paul District has completed a cultural resources literature search, records review, and reconnaissance-level survey of the area. Thirty-three historic and prehistoric sites were identified within the cities' limits. These sites should be considered during implementation, and project plans should be coordinated with the North Dakota and Minnesota State Historic Preservation Offices. Additional cultural resource surveys may be needed before construction.

Recreation opportunities and impacts on existing facilities should be considered in any implementation plans; for instance, trail systems might follow project rights-of-way. Turbulence and undertow in the tail water of low-head dams can be hazardous to swimmers and small craft. Plans for future dam rehabilitation should include consideration of crest or spillway changes to reduce the danger, or barriers should be installed to reduce unauthorized access.

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STAGE 2 WATER SUPPLY STUDY

PROBLEM IDENTIFICATION/ALTERNATIVE FORMULATION/EVALUATION

INTRODUCTION

GENERAL

The St. Paul District, Corps of Engineers, is currently conducting the Grand Forks-East Grand Forks Urban Water Resources Study. The overall study, scheduled for completion in 1980, will identify existing water resource problems in the urban study area, project water resource needs, and provide alternative plans and programs to best meet those needs.

This report focuses on identifying problems and needs and formulating alternative plans to meet the needs for water supply in the urban study area.

SCOPE

The specific scope of this report includes:

1. Review of existing information to identify:
    a. Sources of existing water supplies.
    b. Capacity and quality of existing supplies.
    c. Factors affecting dependability of existing water supplies.
2. Projection of future water supply demands considering:
    a. Historic water use in the study area.
    b. Current water supply and treatment plans and the projections contained therein.
    c. Quality requirements for alternative water uses.
3. Identification of water supply and treatment needs in the area by describing a no action alternative and projecting consequences. Attention focuses on:
    a. Adequacy of known supplies to meet need.
    b. Ability of existing treatment to meet standards.
    c. Ability of water transmission lines to meet needs.

4. Identification of alternative means to meet needs identified in item 3. Major attention is focused on:
   a. Determination of alternative supply sources, both ground and surface.
   b. Determination of major water treatment facility expansion needs to meet future requirements.
   c. Alternative transmission lines to bring water from the source to the treatment facility.

In addition, first level conceptual costs and impacts of the alternatives considered are presented.

STUDY AREA

The urban study area as established for the Grand Forks-East Grand Forks urban area (1) includes Grand Forks, Huntsville, Rhinehart, and Sullivan Townships of Polk County, Minnesota, and Blooming, Brenna, Chester, Falconer, Ferry, Grand Forks, Mekinock, Oakville, and Walle Townships of Grand Forks County, North Dakota (see figure 1). Major population centers in the study area are the cities of Grand Forks, North Dakota, and East Grand Forks, Minnesota, and the Grand Forks Air Force Base near Emerado, North Dakota. A comprehensive overview of the study area is provided in reference 2.

The study area is in the Red River of the North river basin (shown on figure 2). The major rivers in the basin that affect the study area are the Red River of the North and the Red Lake River. The Garrison Diversion Unit to the west of the river basin may, in the future, be used to supply water to the basin.

CLIMATE

Groundwater levels and surface water runoff are influenced by precipitation and evaporation; therefore, these climatological factors are summarized here. The average annual precipitation for Grand Forks for the 69 years ending in 1966 is 20.0 inches. The average precipitation for the calendar year is First Quarter - 1.9 inches,

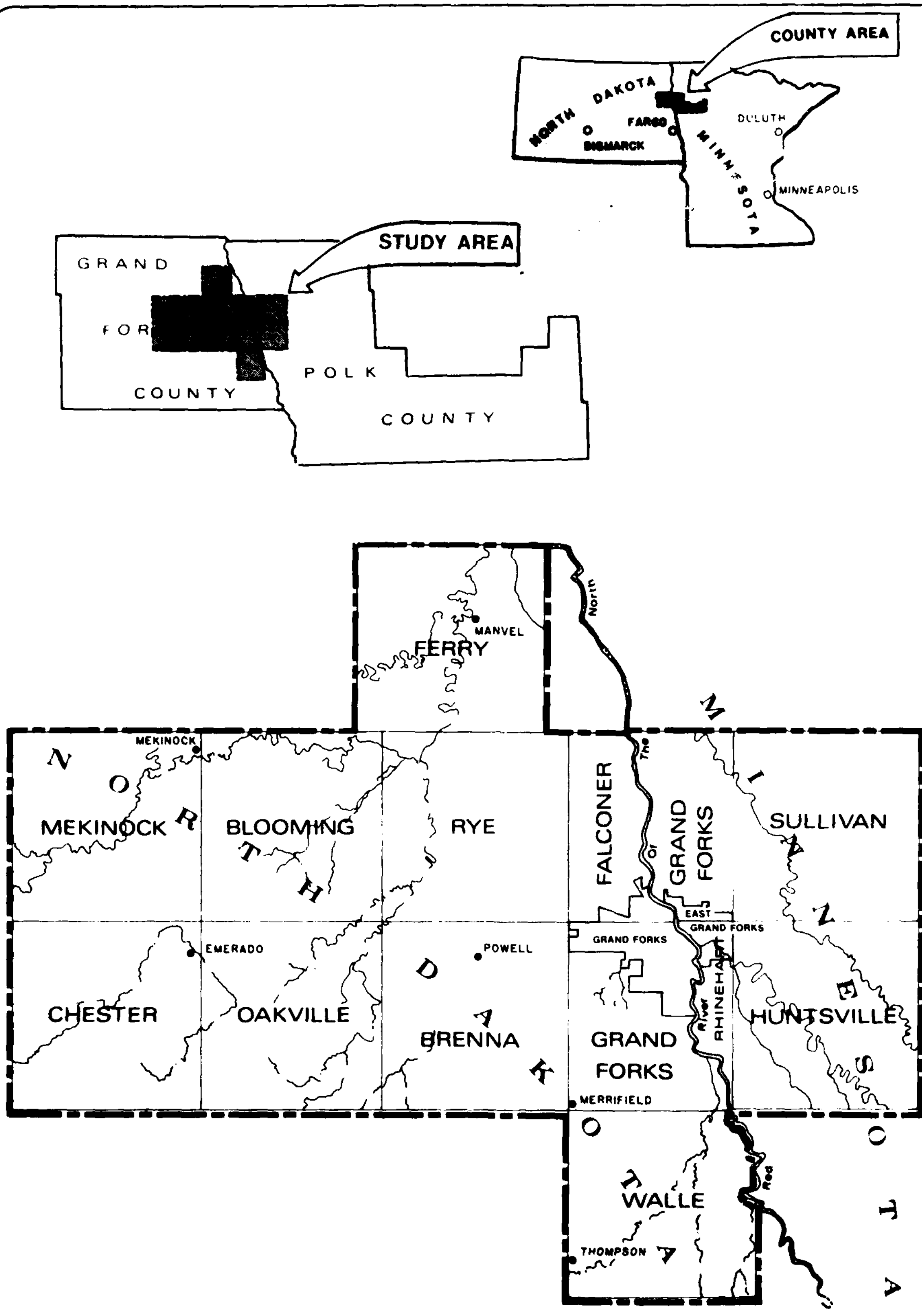


Figure 1 - Study Area

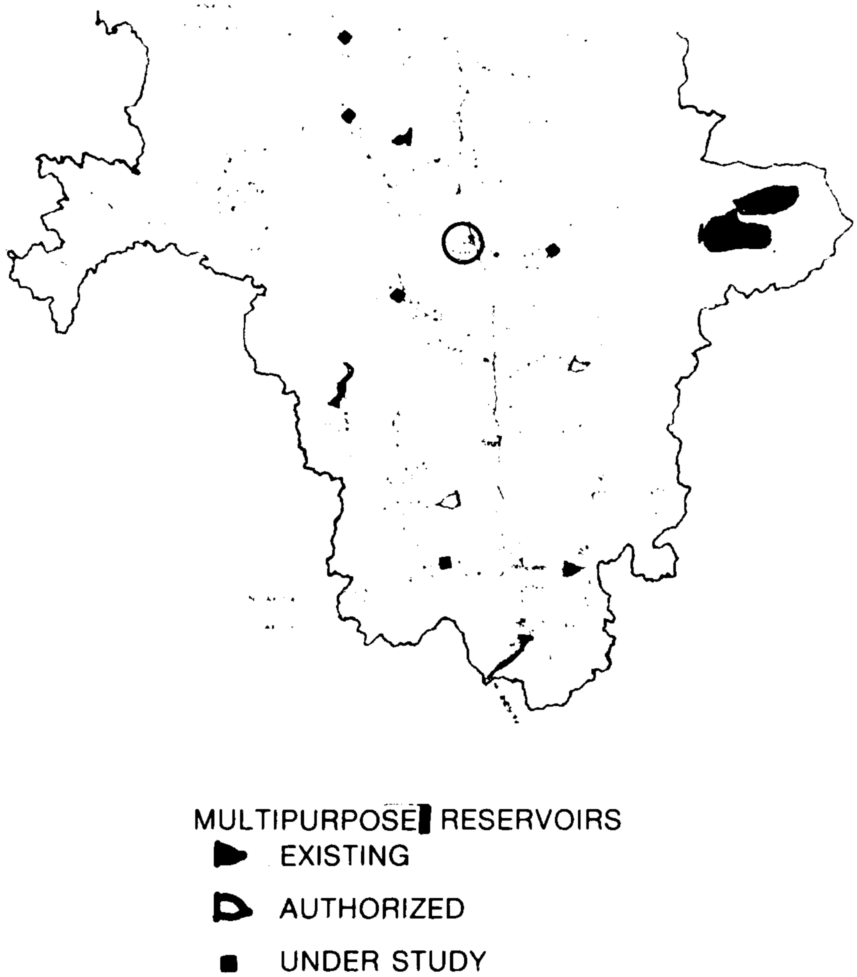


Figure 2 - Red River Basin

Second Quarter - 7.5 inches, Third Quarter - 7.9 inches, and Fourth Quarter - 2.8 inches. The minimum annual precipitation for the 69 years mentioned above was 9.4 inches in 1910 (2).

The mean annual evaporation minus mean annual precipitation is about 8 inches (3). For Orwell Lake, Red Lake, Baldhill, and Homme Reservoirs, average net evaporation (evaporation minus precipitation) in 1936 was 28.2 inches (4). The year 1936 had the highest average net evaporation for these reservoir locations for the period 1929 to 1976.

EXISTING AND POTENTIAL WATER SUPPLY SOURCES

GENERAL

The major urban areas within the study area use the Red Lake River and the Red River of the North to supply the water needs of residential, commercial, and most industrial users. The smaller communities and many rural residents use various groundwater aquifers as their water supply. This section reviews these and other water supply sources available to meet the projected needs of the study area.

PRIOR STUDIES

The Souris-Red-Rainy Basins Comprehensive Study done in 1970 (8) examined water demands and water availability for the study area. Information from this study is summarized in table 1. These data are updated in this study. Also included in the study were projections of water supply demands and minimum desired flow requirements for fishery and aesthetic value at Grand Forks-East Grand Forks. These are also presented in table 1.

The ability of the existing reservoirs to satisfy 1980 required withdrawals, minimum base flows, and desired flow in the river as they would have been influenced by the water availability in the 1930 to 1970 period (includes the drought) were also analyzed, based on the low-flow analysis program and assumptions used. The required flow at Grand Forks would be met in each year with no shortages under two conditions of reservoir operation. One system of operation was projected to result in 1 year of shortage in the 40-year period. The duration of this shortage was estimated at 2 months. The analysis indicated that the existing reservoirs would meet 1980 basic required flows (17.8 mgd (million gallons per day)) at Grand Forks-East Grand Forks. According to the results, the desired flows (for fishery and aesthetic value, 310 mgd) would not be available in 11 of the 40 years and an average of 6 months of shortage (where the average monthly flow was below the desired level) each of those 11 years would

Table 1 - Water demands and water supply facilities for the study area from Souris-Red-Rainy Basins Comprehensive Study, 1970

	Grand Forks	East Grand Forks	Grand Forks - East Grand Forks		
	1970	1970	1970	1980	2000
Water Treatment Plant Capacity	9.0 MGD[1]	4.0 MGD			
Average Water Use	5.75 MGD	1.0 MGD			
Maximum Day Water Use	10.00 MGD	1.5 MGD			
Population Served (1970)	49,500	8,300			
Elevated Storage	1.2 MG	0.6 MG			
Pumped Storage	3.8 MG	1.06 MG			
Projected Municipal and Industrial			8.0 MGD	8.8 MGD	11.7 MGD
Projected Other Demands[2]			3.2 MGD	3.8 MGD	5.0 MGD
Minimum Base Flow in Red River[3]			5.2 MGD	5.2 MGD	5.2 MGD
Minimum Desired Flow in Red River[3, 4]			321.2 MGD	322.6 MGD	326.7 MGD

[1]MGD - Million gallons per day.

[2]Livestock watering, power withdrawal, irrigation withdrawal.

[3]Below confluence of Red Lake, included as safety factor in meeting needs of the area.

[4]Equals 20 percent of the historic average flow of the river plus withdrawals. A flow (310 MGD) equal to 20 percent of the historic average satisfies fisheries demands.

Source: References (8) and (9).

occur. The low flow reservoir system analysis is being updated, therefore the information presented here may change when the updated results are made available (5).

The purpose of the Souris-Red-Rainy Basins Comprehensive Study was to assist the Region in providing a strong and viable social, cultural, and economic structure by delineating those elements of management and development of water and related land resources that could be accomplished in the 10 to 15 years following 1972. The current study deals with determining the water supply needs and analysis of alternatives for meeting these needs for the Grand Forks-East Grand Forks urban area only. This study will consider the capability of sources of supply, various treatment methods, and distribution facilities for meeting the projected 20-year and 50-year water supply demands.

Information provided herein updates information on municipal and industrial demands and analyzes the minimum flow that would be available to the study area during low river flow periods.

SURFACE WATER SUPPLIES

The Red River of the North and the Red Lake River are the only significant surface water supplies internal to the study area. Both rivers are subject to flow regulation via reservoir operation. A considerable volume of information is available in the literature (6)(7)(8) describing the watersheds of these two rivers. The Garrison Diversion Unit is a possible water supply source if political and engineering considerations can be worked out satisfactorily. Pertinent information for defining the adequacy of these rivers for water supply purposes are outlined below.

Red Lake River

The drainage area of the Red Lake River watershed is 5,750 square miles upstream of East Grand Forks. The area draining to the lakes is 1,950 square miles. Upper Red Lake has a surface area of 168.5 square miles, a maximum depth of 20 feet, and an average depth of 3 feet. Lower Red Lake has a surface area of 245.6 square miles, a maximum depth of 35 feet, and an average depth of 18 feet.

During dry years, the evaporation from the lakes has been estimated at 25 inches of water or 1.8 cfs (cubic feet per second) per square mile of lake surface. The tremendous surface area of the lakes allows wind and wave action to cause a fluctuation of water surface of over 1 foot at the controlled outlet from the Lower Red Lake (7).

The operation of the Red Lakes is regulated in accordance with a treaty with the Red Lake Band of Chippewa Indians. When the level of the Red Lakes is between 1,173.5 and 1,172.0, the outflow is regulated to not exceed 50,000 acre-feet annually. When the lake level is below the minimum conservation pool elevation of 1,171.0, the maximum release from the reservoir is 15 cfs and the minimum is 5 cfs as specified in the treaty. Elevation and storage for the lakes is given below (9):

Condition	Elevation (feet)	Storage (acre-feet)
Top of Flood Control Level	1,176.4	2,510,000
Top of Conservation Pool[1]	1,174.0	1,810,000
Top of Buffer[2] (1/2)	—	1,386,500
Minimum Conservation Pool	1,171.0	963,000
Bottom Level of Control	1,169.6	570,000

Below the outlet works of Lower Red Lake, the Red Lake River flows westerly for 196 miles to East Grand Forks. It has been estimated that about 15 cfs of water is lost at low flow because of channel (evaporation and transmission) losses by the time the river reaches the study area. About two-thirds of this loss occurs below Crookston (9). The 75-year average discharge of the Red Lake River at Crookston is 1,121 cfs (10). The 1-in-10-year low mean annual flow is 230 cfs and the 1-in-100-year low

[1] Drawdown of conservation pool begins in November and ends in March at a level of 1,667,500 acre-feet to provide 842,500 acre-feet of storage for flood control.

[2] The storage between the top of buffer and the bottom level of control can only be used to meet the basic withdrawal requirements and not the much higher desired flows (310+ MGD) needed to maintain sanitary and aesthetic in-stream conditions.

mean annual flow is 50 cfs (7). At Crookston, the 1-in-10-year, 7-day low flow is 18 cfs and the 1-in-50-year, 7-day low flow is 4 cfs. Low flow, important in evaluating the adequacy of the river as a water supply, for various frequencies and durations less than 1 year are provided on figure 3.

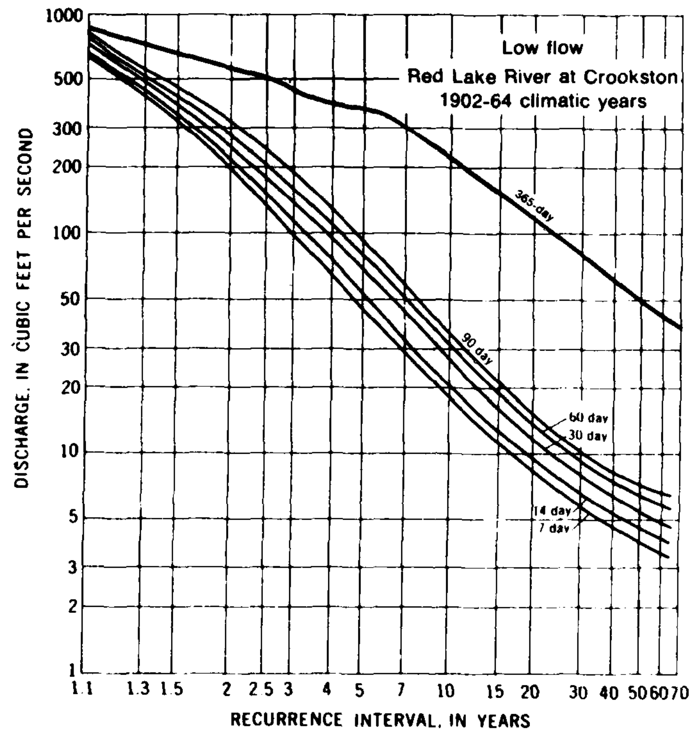


Figure 3 - Low-Flow Frequency - Duration, Red Lake River

In evaluating flow available at Grand Forks-East Grand Forks for a water supply, it is important to have some concept of upstream water use demands. Water use demands are being examined in detail for the

main stem and major tributaries of the Red River as part of the Red River of the North Basin Study (11). Completed studies will update information contained in the Souris-Red-Rainy River Basins Comprehensive Study (8). Preliminary values are presented in table 2. Future demands for the Red Lake River subbasin in the year 2020 have also been projected. These projections (11) indicate a subbasin total river supplied municipal demand of 3.7 mgd (5.74 cfs) and industrial demand of 1.4 mgd (2.17 cfs) in that year. With Crookston converting to a groundwater supply in about 1980, it is estimated that a consumptive use of about 1.9 mgd (2.95 cfs) will occur in 2020. This estimate ignores irrigation demands as the use of water for this purpose in dry years can be controlled by the Minnesota Department of Natural Resources by cancelling riparian irrigation permits to insure that municipal and domestic users obtain the water they need (8). The consumptive use may be greater than this figure if Crookston withdraws its water from an alluvial aquifer. Withdrawing water from the alluvium may reduce runoff and may also induce groundwater recharge from the river.

The only major water development project considered to augment water supply has been Huot Lake which would supply a minimum release of 9 cfs to the study area. This project has been judged unacceptable from both an environmental (14)(15) and economic (16) standpoint.

The problem for the study area is that if the release from the Red Lakes is limited to 15 cfs via treaty obligations, and if channel losses between the lakes and the study area are 15 cfs, and if a drought of the 1930's variety [frequency of at least 1-in-150 years (17)] occurred again, there would be essentially no water to supply the needs of the study area from the Red Lake River. The people in the study area may have to deal with outside units of government to effect a change in release rates from the Red Lakes. Further attention will be given in this report to defining the water use demands of the study area for consideration in the Red River of the North Basin Study.

Table 2 - Red Lake River water withdrawals and return flows below the Lower Red Lake Dam and upstream of East Grand Forks in 1976

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
Withdrawals (MGD)												
Municipal												
Thief River Falls	0.95	1.13	0.97	1.01	1.08	1.23	1.48	1.12	1.16	1.15	1.04	1.00
Crookston[(1)]	1.60	1.60	1.60	1.20	1.00	1.00	1.00	1.00	1.60	1.60	1.60	1.60
Other	0.19	0.27	0.21	0.22	0.21	0.21	0.22	0.22	0.20	0.22	0.21	0.21
Industrial												
At Crookston	1.6	1.4	0.6	0	0	0	0	0	1.0	1.4	1.4	1.6
Irrigation[(2)]	0	0	0	0	0.89	1.77	9.44	6.91	3.71	0	0	0
Other[(3)]	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
Return Flow (MGD)												
Municipal												
Thief River Falls	0.69	0.91	0.71	0.76	0.79	0.93	1.08	0.82	0.88	0.84	0.78	0.73
Crookston	1.20	1.20	1.20	0.90	0.90	0.75	0.75	0.75	1.20	1.20	1.20	1.20
Other	0.16	0.24	0.18	0.19	0.18	0.18	0.19	0.19	0.10	0.19	0.18	0.18
Industrial	0	0	0	0	0	0	0	0	0	0	0	0
Irrigation	0	0	0	0	0	0	0	0	0	0	0	0
Other	0	0	0	0	0	0	0	0	0	0	0	0
Total Withdrawal	5.04	5.10	4.08	3.13	3.88	4.91	12.84	9.95	8.37	5.07	4.95	5.11
Total Return	2.05	2.35	2.09	1.85	1.87	1.86	2.02	1.76	2.18	2.23	2.16	2.11
Consumptive Use	2.99	2.75	1.99	1.28	2.01	3.05	10.82	8.19	6.19	2.84	2.79	3.00

(1) City's converting to a groundwater system which should be operational in 1980.

(2) Primarily wild rice below the Lower Red Lake Dam.

(3) Primarily livestock watering.

Source: Stanley Consultants and St. Paul District Corps of Engineers

Red River of the North

The contributing drainage area of the Red River of the North upstream of its confluence with the Red Lake River at Grand Forks is 20,550 square miles. Three existing reservoirs, Lake Ashtabula, Orwell Lake, and Traverse Lake (see figure 2 for location) regulate flow to the study area. Storage of these reservoirs is as follows (9):

	Storage (acre-feet)		
	Lake Ashtabula[1]	Orwell Lake[2]	Traverse Lake
Top of Flood Control Level	70,700	14,100	249,500
Top of Conservation Pool	70,700	14,100	112,500
Top of Buffer (1/2)	35,950	7,550	---
Minimum Conservation Pool	1,200	1,000	112,500
Bottom Level of Control	1,200	210	112,500

[1]The minimum release from this reservoir is 3 cfs.

[2]The minimum release from this reservoir is 5 cfs.

The Garrison Diversion Project could be used soon for water supply if there was an extreme need for it. Water can be pumped from Audubon Lake to the McClusky Canal which flows to Lone Tree Reservoir. From the Lone Tree Reservoir, the water can be discharged to the Sheyenne River which flows to the Red River of the North. At present this source of supply would be made available to the Grand Forks-East Grand Forks urban area only if the Governor of North Dakota requested the Water and Power Resources Service to release the water. This project, if completed in the 1980's, would add about 52,300 acre-feet per year to the Red River in a dry year (18). The monthly addition would be as follows:

January	3,400 acre-feet	July	5,500 acre-feet
February	2,800 acre-feet	August	5,800 acre-feet
March	2,700 acre-feet	September	5,700 acre-feet
April	2,800 acre-feet	October	5,000 acre-feet
May	5,400 acre-feet	November	4,200 acre-feet
June	5,100 acre-feet	December	3,900 acre-feet

For the minimum month of March this would be an average flow of 45 cfs.

In addition to the three existing reservoirs, Mantator, Kindred, and Twin Valley Lakes have been investigated as potential reservoir sites (8). A combined additional minimum release of 5 cfs from these potential reservoirs would be available at low flow (9). If the desired flow at Grand Forks is reduced from 310 mgd (480 cfs) to 130 mgd (200 cfs), the existing plus authorized plus prospective reservoirs, excluding Garrison, could supply this lower desired flow plus the 1980 required flows 36 out of 40 years. For the 4 years that a shortage was projected, the average number of monthly shortages was five (9).

The average flow of the Red River of the North downstream of the confluence of the Red Lake River is 2,524 cfs (10), about half coming from the Red Lake River. Low-flow frequency data for this location are shown on figure 4.

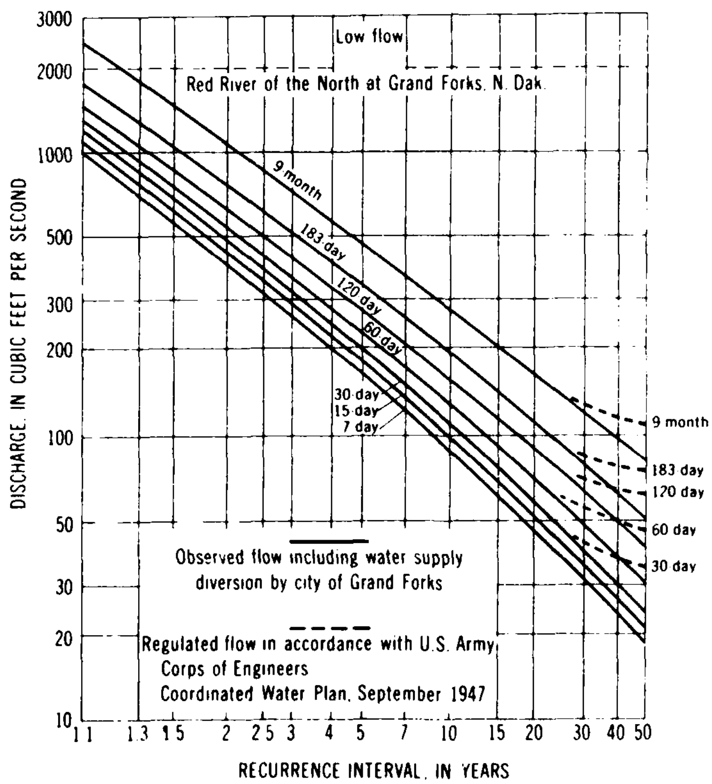


Figure 4 - Low-Flow Frequency - Duration, Red River of the North

As indicated by the dashed lines, low flows are increased by the release of water from Orwell Lake and Lake Ashtabula. Current operating plans of Orwell Lake and Lake Ashtabula call for maintaining a minimum flow of 25 cfs above Fargo, North Dakota-Moorhead, Minnesota. Some of this 25-cfs flow could be transported to the Red River of the North by the Sheyenne River diversion project. There may be as much as another 5 cfs transported to the Red River below Fargo-Moorhead. A channel loss of 10 cfs between Fargo and Grand Forks has been estimated (9). The dependable supply at Grand Forks from the Red River of the North is thus about 15 cfs, less the consumptive water use between Fargo-Moorhead and the study area. Preliminary water use values for 1976 are provided in table 3. Projections of future use indicate a municipal demand of about 35 mgd and a self-supplied industrial demand of about 3 mgd in the year 2020 (increase from present 18 mgd and 2 mgd, respectively) for the area below the reservoirs but above the study area (11).

Irrigation withdrawals can be controlled in extreme dry years; therefore, the available surface water supply from the Red River of the North at Grand Forks is estimated to be about 10 cfs which is about equivalent to the 7-day 100-year low flow, at the present time, but would be only about 6 cfs in the year 2020 as a result of increased consumptive use in the future upstream of Grand Forks. Evaluations in the Red River of the North Basin Study (11) of current operating procedures may indicate more water available as a result of more optimal reservoir operations.

Surface Water Quality

Water quality data were collected from the Red and Red Lake Rivers between 1953 and 1976 (19)(20). The average and range of certain of these water quality indicators are summarized in table 4. As the table shows, many indicators of water quality are fairly similar between the two rivers. The Red River of the North has more dissolved solids, greater hardness and alkalinity, and greater extremes in suspended solids than those in the Red Lake River. These factors would make the Red Lake River slightly superior as a

Table 3 - Red River of the North water withdrawals and return flows below reservoirs and upstream of Grand Forks in 1976

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
Withdrawals (MGD)												
Municipal												
Fargo	7.49	7.55	7.36	7.48	8.56	9.90	11.62	10.56	8.78	8.18	7.47	7.25
Fargo (from Buffalo)	1.60	1.37	1.74	1.59	1.71	1.56	1.83	2.04	1.70	1.79	1.35	1.40
Moorhead	1.21	1.35	1.06	0.88	1.18	1.59	2.02	1.88	1.56	1.15	1.34	1.28
Other	1.74	1.83	1.66	1.77	1.96	2.18	2.53	2.57	2.40	2.10	1.87	1.76
Industrial												
At Fargo/Moorhead	1.49	1.49	1.16	1.33	3.63	3.63	3.63	3.79	3.63	3.79	1.49	1.49
Other	0.56	0.56	0.56	0	0	0	0	0	0.56	0.56	0.56	0.56
Irrigation	0	0	0	0	4.97	10.14	51.15	37.39	21.59	0	0	0
Other	2.22	2.22	2.22	2.22	2.22	2.22	2.22	2.22	2.22	2.22	2.22	2.22
Return Flow (MGD)												
Municipal												
Fargo	0	0	0	5.19	16.43	10.56	10.12	3.71	6.06	12.66	14.90	5.19
Moorhead	2.65	2.72	2.71	3.04	3.55	3.24	3.28	2.94	3.08	3.23	3.11	2.77
Other	1.77	3.06	2.51	3.48	4.43	6.58	1.03	4.74	4.04	3.33	2.48	3.20
Industrial	0	0	0	2.75	1.72	0	0	0	2.41	2.54	0	0
Irrigation	0	0	0	0	0	0	0	0	0	0	0	0
Other	0	0	0	0	0	0	0	0	0	0	0	0
Total Withdrawal	16.31	16.37	15.20	15.27	24.23	31.22	75.00	60.45	42.44	19.79	16.30	15.96
Total Return Flow	4.42	5.78	5.22	14.46	26.13	20.38	14.43	11.39	15.59	21.76	20.49	11.16
Consumptive Use	11.89	10.59	9.98	0.81	-1.90	10.84	60.57	49.06	26.85	-1.97	4.19	4.80

Source: Stanley Consultants and St. Paul District Corps of Engineers

Table 4 - Surface water quality in the study area

Constituent	Red Lake River[1] Average[3]	Red Lake River[1] Range	Red River of the North[2] Average[3]	Red River of the North[2] Range
Physical				
Flow (cfs)	779	75 - 6,530	1,562	310 - 5,470
Turbidity[4] (FTU)	69	2 - 4,500	66	2 - 1,500
Color[5] (units)	30	5 - 100	29	5 - 120
Total Solids[5] (mg/l)	334	28 - 1,500	512	260 - 940
Suspended Solids (mg/l)	51	2 - 410	80	1 - 750
Biological				
Coliform Organisms[4] (#/100 ml)	5,550	20 - 92,000	2,462	20 - 160,000
Fecal Coliform (#/100 ml)	950	20 - 23,000	155	20 - 4,900
Fecal Strep (#/100 ml)	220	10 - 1,100	170	9 - 800
Chemical				
Alkalinity (mg/l as $CaCO_3$)	174	88 - 290	233	96 - 370
Hardness (mg/l as $CaCO_3$)	202	130 - 300	298	140 - 460
Calcium (mg/l as $CaCO_3$)	125	87 - 200	156	89 - 310
Magnesium (mg/l as $CaCO_3$)	63	40 - 90	141	91 - 190
Arsenic[4] (mg/l)	0.009	.001 - .010	0.010	.005 - .023

Table 4 - Surface water quality in the study area (cont)

Constituent	Red Lake River[1]		Red River of the North[2]	
	Average	Range	Average	Range
Barium[4] (mg/l)	0.024	.012 - .050	0.024	.012 - .050
Boron (mg/l)	0.048	.020 - .070	0.110	.080 - .180
Cadmium[4] (mg/l)	0.013	.010 - .210	0.010	.010 - .012
Chromium[4] (mg/l)	0.011	.002 - .020	0.012	.002-.020
Chloride[5] (mg/l)	5.0	0.5 - 18.0	16.7	1.5 - 40.0
Copper[5] (mg/l)	0.012	.010 - .060	0.012	.010 - .040
Iron[5] (mg/l)	1.31	.010 - 17.00	1.88	.04 - 18.0
Lead[4] (mg/l)	0.013	.010 - .130	0.018	.010 - .420
Manganese[5] (mg/l)	0.100	.010 - .640	0.132	.006 - 1.20
Mercury[4] (mg/l)	0.0002	.0001 - .0008	0.0004	.0001 - .0025
Nitrate[4] (mg/l as N)	0.23	.01 - 2.50	0.50	.02 - 4.70
Selemiun[4] (mg/l)	0.006	.001 - .010	0.006	.001 - .010
Silver[4] (mg/l)	0.004	.002 - .010	0.005	.002 - .010
Sulfate[5] (mg/l)	28	9 - 81	40	29 - 180
Zinc[5] (mg/l)	0.064	.010 - 2.8	0.032	.010 - .270

[1]At bridge on State Highway 220 at East Grand Forks.

[2]At Grand Forks Waterworks Intake.

[3]Average values when sampled or average value of samples.

[4]Limited in National Primary Drinking Water Regulations.

[5]Limited in National Secondary Drinking Water Regulations.

Source: Reference (20).

raw water source. However, the higher average biological values in the Red Lake River indicate it is a slightly less favorable water supply source than the Red River of the North, but average values are within permissible limits of 10,000 coliforms/100 ml (milliliters) and 2,000 fecal coliform/100 ml commonly used in evaluating raw water supply suitability. Values may be lower at the present time as a result of increased municipal and industrial wastewater treatment upstream of the study area. At low Red Lake River flows, chemical constituents tend to have concentrations near the high end of the range shown in table 4 (2). Treated water quality criteria and standards are discussed in the section on water supply and treatment needs (beginning on page 40).

The Red Lake River and especially the Red River of the North have extensive periods of high turbidity. These periods are mainly caused by the nature of the streambed (very fine silty clay) and the slow settlement of the colloidal clay after turbulence from fluctuating stream levels and currents suspend the clay in the river (14)(22).

Other Surface Water Sources

The Turtle River (see figure 5) passing through the study area has a drainage area of 730 square miles and storage of 1,325 acre-feet. The Goose River (see figure 2) south of the study area has a series of 41 small dams providing 14,300 acre-feet of storage. Limited storage is available in Marais Creek or English Coulee (see figure 5) watersheds in the study area (20).

The major surface water storage internal to the study area are the wastewater treatment lagoons (see figure 5) of Grand Forks, East Grand Forks, the Air Force Base, and American Crystal Sugar Company. These lagoons could be used as a water supply source only with extensive treatment.

Summary

It is estimated that at extreme low-flow periods about 10 cfs is available from surface water sources to supply the municipal and industrial needs of the study area. Additional water available in waste treatment lagoons could supply water with adequate treatment. During extreme dry years

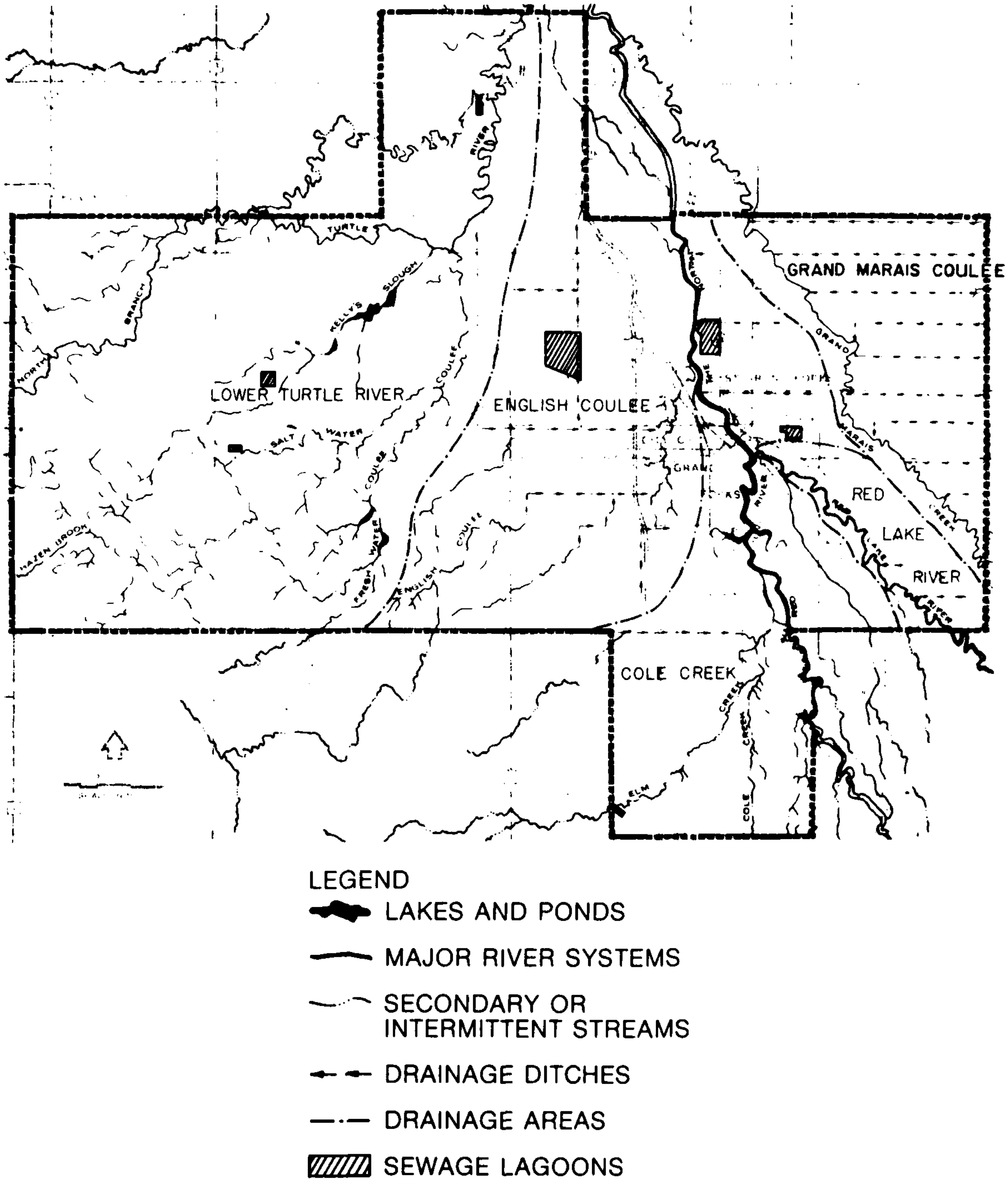


Figure 5 - Water Resources of the Study Area

when net evaporation would be high, as occurred during the 1930's, the wastewater lagoons at Grand Forks, East Grand Forks, and the Air Force Base would be able to supply about 80 days of flow at the current water use rate. Lagoons store water for a time and the return flow to the river is zero at times. As cities increase in size, zero return flows from lagoons to the river may mean users downstream may experience water shortages. During water shortages perhaps Grand Forks and East Grand Forks could buy some water from neighboring rural water utilities or from the Indian Reservation at the Red Lakes. Most potential large-scale reservoir or diversion projects are beyond the capacity of the area to develop. A viable means of increasing surface water supply internal to the study area is construction of off-channel storage reservoirs. Water reuse, the use of water from reservoirs outside the study area, and off-channel storage will be discussed in a later section.

GROUNDWATER SUPPLIES

Groundwater is used by much of the rural population and supplements surface water supplies for some industrial users. Only the Elk Valley and Inkster aquifers to the west of the study area and the Beach Ridge aquifers east of Crookston in Polk County can be relied on to provide an adequate quantity of good quality water. Deposits of glacial Lake Agassiz are generally too fine-grained to be important sources of abundant groundwater (12). The Dakota aquifer underlying much of Grand Forks County is too saline for use as a water supply without extensive treatment. A rather poorly defined aquifer begins immediately north of East Grand Forks and extends two townships east and five townships north. Because this aquifer is relatively close to the study area, it may be worthwhile to do a field study and possibly test drilling in the area, although available information indicates high solids and low well yields

Just north of the Inkster aquifer in Walsh County, North Dakota, is the Fordville aquifer. The Department of Defense has a water rights permit from North Dakota allowing use of 2,000 gpm (gallons per minute) from this aquifer that could be available to the study area. Physical and chemical characteristics of the aquifers that could be tapped by the study area are provided in tables 5 and 6. Locations are shown on figure 6 (2)

Table 5 - Physical characteristics of aquifers

Name	Area (sq miles)	Depth Interval (ft)	Average Thickness (ft)	Estimated Storage (acre-ft)	Potential Yield (gpm)
Sand Bed	290	160 - 175	10	500,000	5 - 50
Beach Ridge	180	10 - 30	10	175,000	10 - 20
Fordville	28	5 - 55	20	100,000	50 - 500
Inkster	11	5 - 70	27	60,000	50 - 500
Elk Valley	200	5 - 75	34	1,300,000	50 - 500
Emerado	15	80 - 110	15	43,000	50 - 500
Grand Forks	20	175 - 215	18	69,000	50 - 250
Thompson	8	121 - 150	25	38,000	50 - 250

Source: Reference (23)

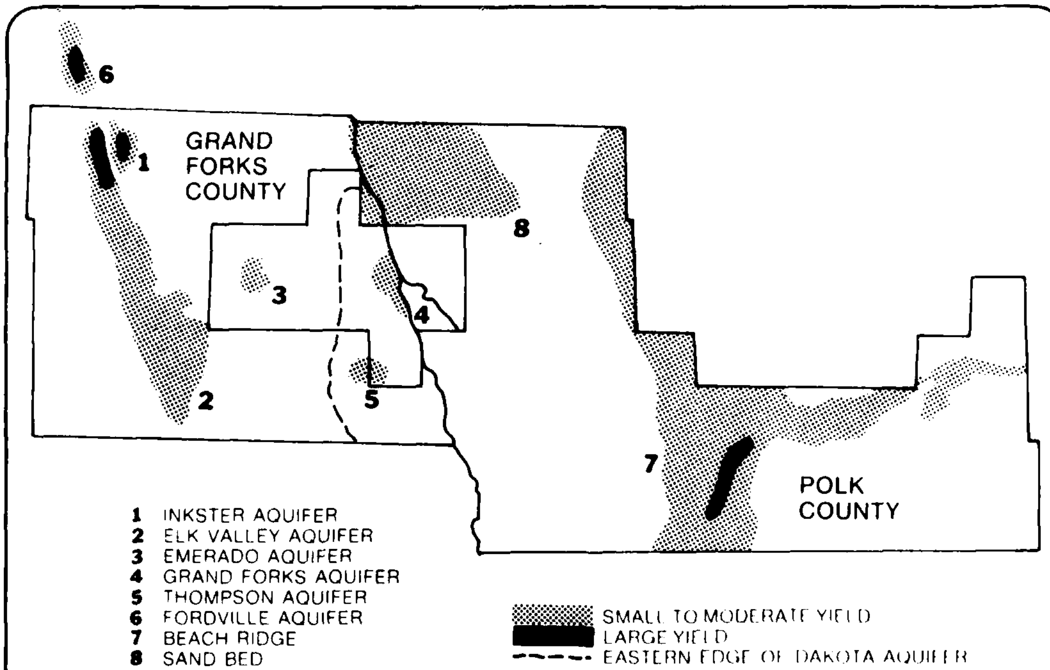


Figure 6 - Major Glacial Drift Aquifers and Yields of Wells Grand Forks and Polk Counties

Table 6 - Representative chemical characteristics of aquifers

Aquifer	User	Depth (ft.)	Iron	Calcium	Magnesium	Sodium	Chloride	Potassium	Sulfate	Hardness	Total Dissolved Solids
			Concentrations (mg/l)								
Grand Forks	Test Hole in Grand Forks	31	4.4	378	213	95	101	8.4	1,530	3,310	2,740
Grand Forks	Pillsbury Co.	294	1.6	1,623	764	823	5,644	--	627	2,387	13,938
Thompson	Test Hole in Thompson	146	1.9	270	111	1,200	1,860	27	970	2,051	4,500
Emerado	Test Hole in Emerado	90	0.22	205	79	289	368	17	733	1,454	1,890
Inkster	Observation Well	74	0.24	79	21	6.5	2	2.8	71	350	306
Elk Valley	Test Hole Near Larimore	58	0.14	90	23	16	16	4.0	63	368	426
Elk Valley	Test Hole at HWY 2 & 18	60	0.12	90	31	19	11	--	86	418	391
Sand Bed	Unknown, Reported saline high total dissolved solids, probably similar to Grand Forks Aquifer.										
Beach Ridge	Unknown, Reported dissolved solids less than 500 mg/l.										
Fordville	Probably similar to Elk Valley quality.										

Source: Reference (24) and Stanley Consultants

A large number of flowing wells exist internal to the study area. Most of these wells are 15 to 30 feet deep and are characterized by total dissolved solids levels over 1,000 mg/l (milligrams per liter). Many other wells ranging in depth from 100 to 160 feet have been drilled. These are characterized by total dissolved solids of 3,000 to 8,000 mg/l. Yields are typically 2 to 10 gpm (24).

In summary, no aquifers internal to the study area can supply an adequate quantity and quality of water to meet urban needs. Two aquifers to the west of the study area, Elk Valley and Fordville, can supply adequate quantities and quality. The Inkster aquifer is probably too small to be developed as a major supply source. Aquifers to the east are more distant than these.

It has been suggested that a groundwater supply source to meet the needs of Grand Forks and the Air Force Base could be developed from the Elk Valley aquifer near McCanna, North Dakota (24).

WATER SUPPLY DEMANDS

GENERAL

The preceding section evaluated the availability of water to the study area from surface and groundwater supplies. This section examines water use demands internal to the study area. The adequacy of existing supply sources and water treatment facilities can be determined if the availability of and demand for water are known.

CURRENT URBAN WATER USE

Information provided by the various cities and water users in the study area has been examined to estimate 1976 urban water use in the study area. This information is presented in table 7 and basically represents surface water use. A limited amount of groundwater is used in the urban area for residential and industrial supply. A review of the information in table 7 indicates the substantive impact that seasonal water use by sugar beet and potato processing facilities has on existing water demand. For August and October 1976, the water use for American Crystal Sugar was greater than the water use for East Grand Forks. For half of the year (August to February), American Crystal Sugar uses more than 50 percent of the water of the whole city of East Grand Forks. From April through July, the water demand for American Crystal Sugar was zero. From November through May, the water consumption of the potato industry was greater than 20 percent of East Grand Forks water use for the same period. The water demand of the potato industry was above its annual average for November through May. June through October are low water use months for the potato processers.

Historic water use is provided in table 8. Variations in water demands are important design considerations in water supply, treatment, and distribution evaluations. Ratios for maximum month to average month and maximum day to average day for Grand Forks and East Grand Forks are provided on the following page (25(29).

Table 7 - Urban water use in the study area, 1976

Water Withdrawals		Water Use in Month (Million Gallons)											
User	Source	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
East Grand Forks	Red Lake River	30.35	29.65	33.10	31.08	34.90	35.25	47.74	42.06	38.38	38.18	34.04	29.55
Grand Forks	Red River	186.64	168.04	179.94	183.78	238.95	218.94	248.68	248.12	210.92	217.71	204.33	198.52
American Crystal	Red Lake River	17.89	7.99	2.13	0	0	0	0	51.81	20.04	51.67	10.29	0.32
Burlington Northern[1]	Red Lake	9.55	8.68	8.68	8.68	6.94	3.47	--	0.88	1.74	2.60	6.94	6.94
Major Users of City Water													
Grand Forks AFB	(GF)	26.53	25.47	31.60	27.03	37.43	45.22	47.40	45.17	37.68	27.00	26.48	34.93
International Co-op	(GF)[2]	1.13	0.59	0.59	0.62	0.56	0.81	0.85	0.52	0.54	14.95	26.93	25.65
University of N. Dak.	(GF)	5.16	5.58	5.74	5.55	6.00	4.84	4.19	4.27	7.18	5.53	8.86	7.24
Pillsbury Co.	(GF)	3.51	4.46	5.77	4.64	3.31	0.40	0.09	0.13	3.27	5.90	5.71	6.32
Bridgeman Creamery	(GF)	0.38	0.54	0.74	1.10	1.39	1.90	1.71	1.85	1.01	0.63	0.62	0.32
Rogers Brothers	(GF)[3]	0.63	1.83	1.88	1.69	1.60	0.87	--	--	--	0.47	2.05	2.41
N. Dak. State Mill	(GF)	1.29	1.22	1.23	1.37	1.23	1.30	1.17	1.40	1.51	1.05	1.24	1.43
Great Northern RR	(GF)	1.60	1.59	1.75	1.87	2.00	1.35	0.98	0.92	1.05	1.60	2.07	1.64
United Hospital	(GF)	0.22	0.26	0.30	0.32	1.04	3.36	3.63	3.37	3.38	2.34	2.10	2.20
American Crystal	(EGF)	5.15	6.30	5.08	1.75	0.48	0.45	5.83	6.74	9.50	17.73	17.48	21.57
Ryan Potato[4]	(EGF)	0.77	0.63	0.49	0.79	0.91	0.49	0.11	--	--	0.30	0.72	0.70
Burlington Northern[5]	(EGF)	9.04	8.54	9.29	8.79	6.02	2.20	0.47	1.37	1.08	3.36	3.64	3.60

[1]Limited information is available for the Burlington Northern Industrial area in East Grand Forks. The values reported here are maximum monthly use in 1970-71 when King of Spuds and Old Dutch were big water users. With King of Potatoes and Northern Potato now operating, the water use may be less than values indicated.

[2]Water use averaged 28.2 million gallons/month from January 1977 to May 1977, which is more representative of future use than values reported as actual use in 1976 above.

[3]Reported no longer in operation, July 1977.

[4]1974 data.

[5]1974 data for city water supply to King of Spuds and this industrial area.

Source: Stanley Consultants

Table 8 - Historic urban wate~ use

Year	1970	1971	1972	1973	1974	1975	1976
				Flows (MGD)			
East Grand Forks							
Average Daily Use[1]	0.753	0.740	0.89	0.877	0.866	0.883	1.165
Average Commercial & Industrial Use	0.366	0.359	--	--	0.452	--	0.440
Average Residential Use	0.387	0.381	--	--	0.414	--	0.725
Grand Forks							
Average Daily Use[1]	4.870	5.844	6.258	6.162	6.320	6.060	6.549
Average Supply to Air Force Base	1.070	1.06	1.21	1.24	0.96	0.81	1.13
Average Industrial Use	0.82	1.12	1.30	1.33	1.36	0.94	1.16
Average Residential Use	2.98	3.66	3.75	3.59	4.00	4.31	4.26

[1] Average daily use is the amount of water in each city delivered to the distribution system. From 10 to 15 percent more raw water intake has been required in the past due to losses in water treatment. The recent addition (August 1977) of the water treatment sludge and filter backwash water treatment facility should reduce this for Grand Forks. The water use reported here is higher than water billed in each city due to unaccounted for losses in the distribution system. These are estimated at 5 to 10 percent based on Grand Forks data.

Source: Stanley Consultants

	Grand Forks	East Grand Forks
Ratio Maximum Month to Average Month	1.19	1.24
Ratio Maximum Day to Average Day	1.50	1.75

PROJECTED WATER USE

The existence of major seasonal water using industries and the Grand Forks Air Force Base in the study area make projections of future water demands difficult. The projections in this report are based on the following assumptions:

1. The Grand Forks Air Force Base will remain in the area and the estimated water use in the year 2030 will be 1.13 mgd.
2. Future demands for International Co-op and Pillsbury Company will be based on 0.80 mgd and 0.21 mgd, the city-supplied portion of water use projections made by the industries.
3. Industrial demands for other industries (as shown in table 9) are based on the average day in the maximum month of industrial use and the projected values in references (25) and (26). The estimated sugar beet production increase by the year 2020 is about 195 percent. Officials of American Crystal Sugar have stated that the size of their plants are expected to increase and become more efficient. American Crystal Sugar expects the net result to be no increase in water use over present levels. By the year 2020, potato production and poultry product industries are projected to increase about 125 percent and 160 percent, respectively. Indications are that the processing season will increase and may evolve into year-round processing (16).
4. Remaining commercial and residential demands will be based on 100 gcpd (gallons per capita per day) and population forecasts given below (28):

	1975	1980	1990	2000	2010	2020	2030
Grand Forks	41,986	45,409	53,545	62,128	72,296	83,976	97,351
East Grand Forks	8,397	9,279	10,737	12,376	14,463	16,800	19,475

The 100 gpcd value is near current use rates in both cities (25)(29) for residential and minor commercial water use and includes distribution losses.

5. Maximum daily and monthly values will be assumed to occur in the same ratios as currently experienced. These ratios are stated in the first part of this section. Seasonal use of water by residential and commercial users will be assumed to follow present trends. These trends are illustrated on figure 7.

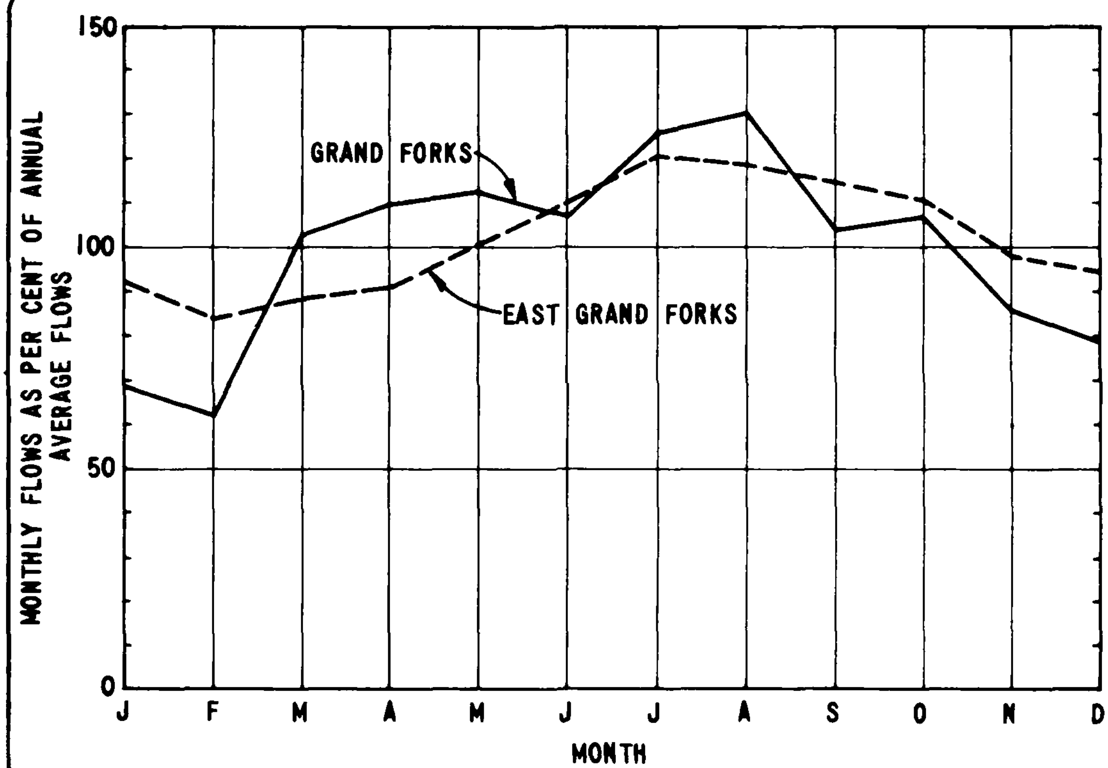


Figure 7 - Seasonal Water Use Trends for Grand Forks and East Grand Forks

With these factors and assumptions considered, projections of urban water supply demands from the present to the year 2030 have been made. Results of projections of water supply demands for the urban area are shown in table 9. Total river water supply needed to meet urban demands for the average and maximum day are sums of Grand Forks and East Grand Forks demands plus the surface water use by the self-supplied industries of American Crystal Sugar and Burlington Industrial. The quality requirements for future users will be a water treated similar to existing water treatment for about 90 percent of the projected demand. Remaining use (cooling water) can use untreated river water to meet needs. Alternative supply sources will also affect the degree of treatment required. Little treatment of groundwater from the Elk Valley or Fordville aquifer would be required. Softening of these waters, if used, may be desirable. Extensive treatment would be required to render either locally available groundwater or wastewater suitable for use. Use of groundwater available internal to the study area for industrial purposes would adversely affect the operation and performance of existing wastewater treatment facilities.

Table 9 - Projected water demands

	Annual Average 1976	Design Flow (MGD)						
		1976	1980	1990	2000	2010	2020	2030
Self-Supplied								
American Crystal	0.45	1.67	1.67	1.67	1.67	1.67	1.67	1.67
Burlington Industrial	0.18	0.32	0.32	0.32	0.32	0.32	0.32	0.32
Pillsbury	0.15	0.21	0.21	0.21	0.21	0.21	0.21	0.21
City Supplied Users								
Grand Forks								
Grand Forks Air Force Base	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13
International Co-op	0.58	0.80	0.80	0.80	0.80	0.80	0.80	0.80
Pillsbury	0.12	0.21	0.21	0.21	0.21	0.21	0.21	0.21
University of North Dakota	0.19	0.29	0.29	0.29	0.29	0.29	0.29	0.29
Bridgeman	0.03	0.05	0.05	0.05	0.05	0.05	0.05	0.05
State Mill	0.04	0.05	0.06	0.06	0.06	0.06	0.06	0.06
Great Northern	0.05	0.07	0.07	0.07	0.07	0.07	0.07	0.07
United Hospital	0.06	0.12	0.12	0.12	0.12	0.12	0.12	0.12
Other Industry	--	--	0.10	0.21	0.50	0.75	1.00	1.25
East Grand Forks								
American Crystal Sugar	0.27	0.73	0.75	0.75	0.75	0.75	0.75	0.75
Ryan Potato	0.02	0.03	0.05	0.05	0.05	0.05	0.05	0.05
Burlington Industrial	0.15	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Other Industry	--	--	0.20	0.30	0.40	0.50	0.60	0.70

Table 9 (cont)

	Annual Average 1976	Design Flow (MGD) 1976	1980	1990	2000	2010	2020	2030
City Residential & Commercial (Average Annual)								
Grand Forks	4.26	4.20	4.54	5.35	6.21	7.23	8.40	9.74
East Grand Forks	0.73	0.84	0.93	1.07	1.24	1.45	1.68	1.95
Average Total City Demand								
Grand Forks	6.46	6.92	7.37	8.29	9.44	10.71	12.13	13.72
East Grand Forks	1.17	1.90	2.23	2.47	2.74	3.05	3.38	3.75
City Total Demand Maximum Day[1]								
Grand Forks	--	9.05	9.64	10.97	12.55	14.33	16.33	18.59
East Grand Forks	--	2.53	2.93	3.27	3.67	4.14	4.64	5.21
Total River Water Supply Needed to Meet Urban Demands								
Average Day	--	11	12	13	14	16	18	20
(cfs)	--	(17)	(19)	(20)	(22)	(25)	(28)	(31)
Maximum Day	--	14	15	16	18	21	23	26
(cfs)	--	(22)	(23)	(25)	(28)	(33)	(36)	(40)

[1] Equals 1.75 x city residential and commercial plus city supplied industries in East Grand Forks and 1.50 x city residential and commercial plus city supplied industries in Grand Forks.

Source: Stanley Consultants

REVIEW OF EXISTING WATER SYSTEM FACILITIES

GENERAL

The section beginning on page 6 projected water supply that would be available to the study area in future years. The previous section projected water supply demands of the study area. This section summarizes information on existing water treatment and distribution facilities.

URBAN WATER SYSTEM FACILITIES

A schematic of existing water supply, treatment, and distribution facilities for the urban study area (26)(29)(31) is shown on figure 8. The figure indicates that the municipal systems of Grand Forks and East Grand Forks are interconnected so that treated water can be transferred between the cities.

Water Treatment Plants

The rated capacity of a water treatment plant is based on the filtering rate used for design purposes. The rated capacity of the East Grand Forks plant is 4.0 mgd, based on a filter rate of 2 gpm/ft^2 (gallons per minute per square foot). At flow rates above 3.0 mgd, there are problems holding the sludge blanket down in the precipitator clarifiers (32). These clarifiers appear to be the units that limit the plant flow rate. Chemical feed units, pumps, and other treatment units are capable of functioning properly at plant flow rates of 4.0 mgd.

The rated capacity of the Grand Forks water treatment plant is 12.0 mgd based on a filter rate of 3.0 gpm/ft^2. The higher filter rate at Grand Forks is due to the use of mixed-media filtration (added in 1976 in the 1958 plant). Normal design standards used by the North Dakota Department of Health are 2 gpm/ft^2. The trend is to allow higher filtration rates of up to 5 gpm/ft^2 with mixed-media filtration which could be used to increase filtration capacity. Other treatment units may be hydraulically overloaded at plant flow rates higher than 12.0 mgd.

Both treatment facilities use basically the same concept. Treatment steps involved include addition of powdered activated carbon and alum for turbidity reduction and taste and odor control followed by two stage lime-soda ash softening to reduce hardness and filtration to meet quality standards for turbidity and chlorination. Flow diagrams for the two plants are shown on figure 9. The East Grand Forks plant is typically operated 8 to 10 hours per day, while the Grand Forks plant is operated 24 hours per day.

Water Storage Facilities

The capacity of water storage facilities in each city and at the Air Force Base is shown on figure 8. Total capacity of all storage is 17.9 million gallons, 1.4 million gallons at the Air Force Base, 12.4 million gallons at Grand Forks, and 4.1 million gallons in East Grand Forks.

Water Distribution System

An analysis of the water distribution system internal to East Grand Forks, Grand Forks, or the Air Force Base is beyond the scope of this phase of the Grand Forks-East Grand Forks Urban Study. Figure 10 shows the boundaries of the water systems for Grand Forks, East Grand Forks, and the Air Force Base. There is at present only one supply line from Grand Forks to the Air Force Base. If this line ruptured or became unusable, there would be water shortage problems on the base. It could become critical if a fire broke out at the Air Force Base. A second pipeline from Grand Forks to the base would substantially increase the water supply reliability to the base.

Water Supply Pumping Stations

The design capacity of the raw water intake structure for East Grand Forks is 4.0 mgd. The capacities for the three Grand Forks intakes are 8.6 mgd, 5.5 mgd, and 10.0 mgd for the Red Lake intake, Red River Intake No. 1 (RR1), and Red River Intake No. 2 (RR2), respectively. A Red River intake for East Grand Forks has been proposed (29).

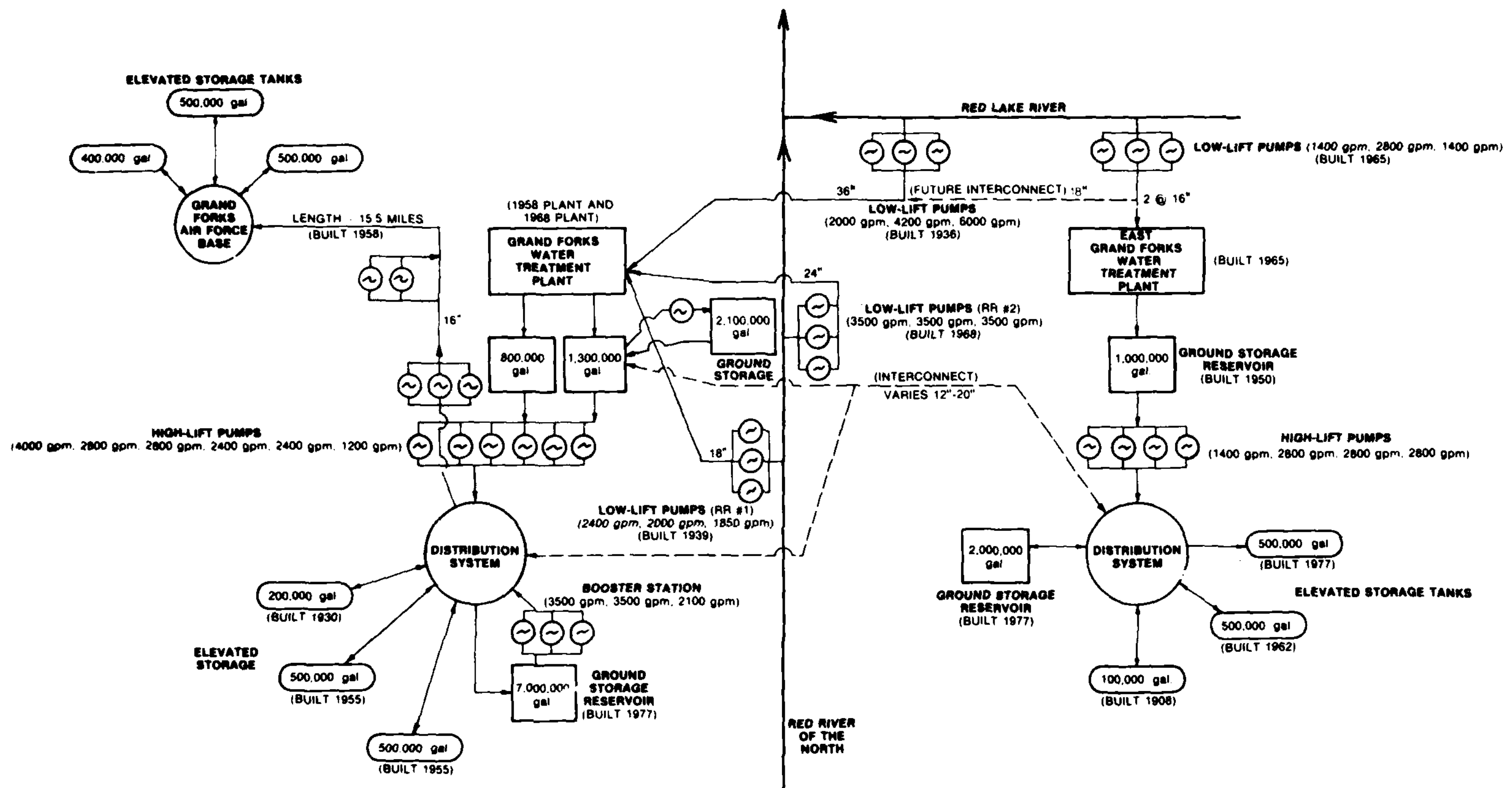
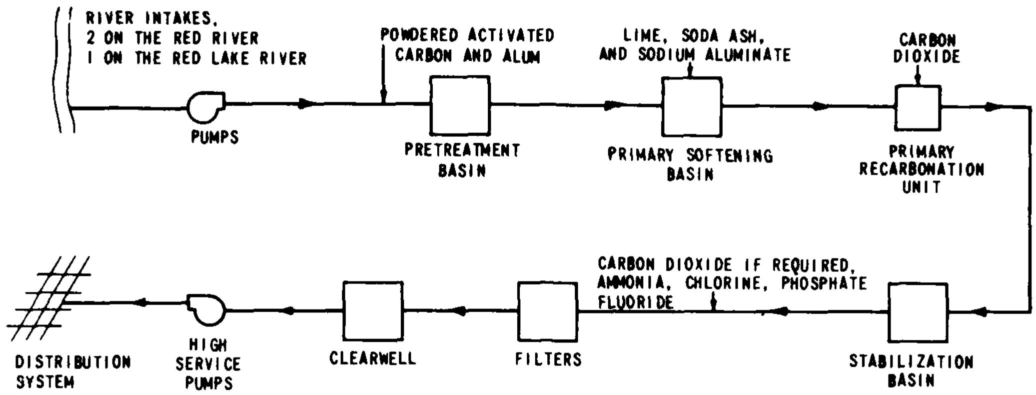
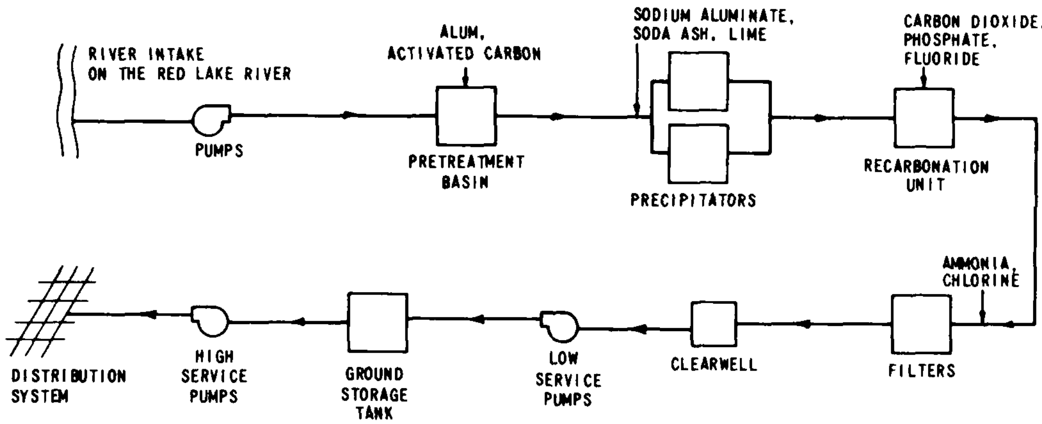


Figure 8 - Schematic of Existing Water System Facilities



a) GRAND FORKS WATER TREATMENT FLOW DIAGRAM



b) EAST GRAND FORKS WATER TREATMENT FLOW DIAGRAM

Figure 9 - Flow Diagrams of the Grand Forks and East Grand Forks Water Treatment Plants

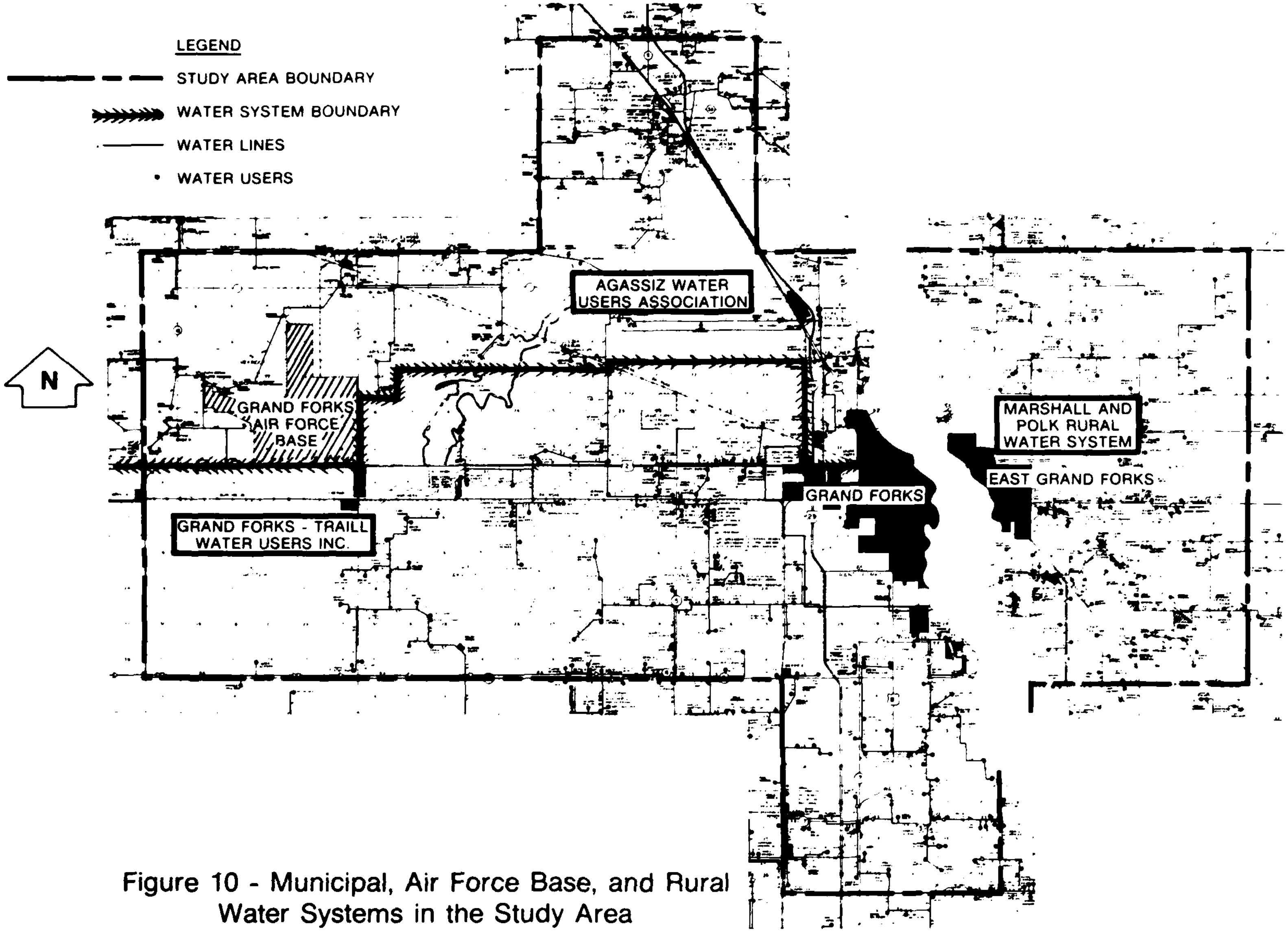


Figure 10 - Municipal, Air Force Base, and Rural Water Systems in the Study Area

The water supply dam at Grand Forks creates a pumping pool for intakes RR1 and RR2. This dam is deteriorating, and proposals to make temporary repairs prior to possible new dam construction have been made to ensure continued system operation.

Water Treatment Plant Residue

Both Grand Forks and East Grand Forks have examined options and implemented programs for treatment of filter backwash and lime sludge disposal. Both systems meet requirements of the NPDES (National Pollutant Discharge Elimination System) permits for their facilities.

OTHER WATER SYSTEMS OF THE STUDY AREA

Three rural water systems operate in the study area. These are the Agassiz Water Users Association, the Grand Forks-Traill Water Users, Inc., and the Marshall and Polk Rural Water System (2).

The Agassiz Water Users Association obtains its raw water from the Inkster aquifer from wells located in Section 23 of Inkster Township, Grand Forks County, North Dakota (33). Water is supplied to a number of rural residents and small communities including Mekinock and Manvel, North Dakota, and unincorporated areas including Oscarville and La Moine, North Dakota, just north of Grand Forks. The water distribution system consists of 6-inch and smaller lines.

The Grand Forks Traill Water Users, Inc., similarly supplies water to rural residents and smaller communities. The source of water is the Elk Valley aquifer from a well field (700 gpm) located in Section 3 of Avon Township, Grand Forks County, North Dakota (34). The system serves the communities of Thompson and Merrifield, North Dakota, in the study area, as well as several subdivisions south of Grand Forks and several business establishments and small residential areas west of Grand Forks along Highway 2. Average use for the system in 1976 was 32,000 gpd (gallons per day)(2). The system consists of 8-inch and smaller lines. Several reservoirs are located throughout the system similar to the Agassiz system.

The Marshall and Polk Rural Water System supplies mainly rural residents internal to the study area (35).

Emerado is supplied by a well field in the Elk Valley aquifer approximately 8 miles west of the city. Arvilla, North Dakota, is supplied from a branch line from this transmission line (24).

Several industries and other users use nonpalatable well water for various purposes in the study area.

The major problems these other users cause for the study area are:

1. The proximity of the rural water users service areas to the urban areas infringes on the development land available for each city, and the small water line sizes used do not lend themselves to ready incorporation into municipal system extensions.

2. Some of the poor quality well water used by certain industries enters the community's wastewater treatment facilities and causes operational difficulties.

Some residential users use water from cisterns periodically filled by commercial water haulers (2) (water from the city).

WATER SUPPLY AND TREATMENT NEEDS

GENERAL

Prior sections have examined water supply sources, existing and future water demands, and existing water system facilities. This section examines the adequacy of the existing system to meet future needs. Where existing systems cannot meet future needs, a problem or need has been identified for the study area.

ADEQUACY OF WATER SUPPLY

The adequacy of water supply must be evaluated on both a quality and quantity basis. A water supply from the present sources (Red River of the North and Red Lake River) of approximately 10 cfs (which is equivalent to about half the 7-day, 50-year low flow) at present and 6 cfs in 2020 will be available in extreme low-flow conditions. The municipal and industrial demands are 17 cfs now and are projected to increase to 31 cfs in 2030. If nothing is done to increase the size of reliable flows during extreme dry periods, a severe water shortage will occur in the urban area if a severe drought occurs. Current water demands of 17 cfs are almost double the 10-cfs extreme low flow mentioned above and are about equal to the 7-day, 50-year low flow as shown on figure 4. For the no action alternative the urban area should discourage any expansion or be willing to cope with water shortages during severe droughts (1 in 50-year occurrence or more severe).

The second criterion is water quality. Existing chemical quality data are provided in table 4. Quality criteria for raw and treated water are being developed nationally. National primary (36) and secondary (37) standards for drinking water have been proposed pursuant to the Safe Drinking Water Act (Public Law 93-523) and must be met by all private and public water systems. In addition, the U.S. Environmental Protection Agency has proposed standards for surface waters used as water supplies (38).

Both States also have standards for surface water used as water supplies (39)(40). In addition, for this study area, the U.S. Air Force Regulation AF 161-44 for surface water used as a water supply may be important (41). The water treatment processes used at Grand Forks and East Grand Forks have little effect on certain constituents in the raw water (41). These constituents and their criteria are presented in table 10. A review of water quality data for the Red Lake and Red Rivers (20)(42) does not indicate that additional treatment will be necessary to meet standards for pesticides, herbicides and other organic chemicals, and radioactivity because current levels in these rivers are low.

Comparing values in tables 4 and 10 indicates that standards for color, cadmium, lead, and manganese may be difficult to meet at certain times. If wastewater treatment and nonpoint source control improve the water quality of the Red Lake and Red Rivers to the point that water quality standards are met, water supply and treatment standards may be met in the rivers for the urban area.

CAPACITY OF EXISTING WATER TREATMENT SYSTEMS

A water supply is considered adequate if it can deliver the required fire flow for a certain duration fire with consumption at the maximum daily rate (43). The required daily flow at key points in the water distribution system for Grand Forks and East Grand Forks is estimated at 8,000 gpm (11.5 mgd), the designated duration of which is 8 hours (43). Present maximum day demand for Grand Forks and East Grand Forks is estimated at 11.6 mgd in the year 2000 and 23.8 mgd in 2030.

The design capacity of water treatment plants is related to the storage available in the system because the water supply required to satisfy maximum daily demand and fire fighting needs can come from either source. Common practice is to design the water treatment plant for maximum daily demand (44). Current treatment capacity available in the urban area is 15 mgd. Plant expansion in the study area would be needed in about 1990. East Grand Forks would have to shift to 16-hour operating days or more to meet future needs. The capacity of the East Grand Forks system is adequate to meet projected supply needs until about 1990 based on maximum day demand.

Table 10 - Water quality standards[1]

	Air Force Criteria In Raw Water (41)	North Dakota Water Quality Standards, Red River (40)	Minnesota Water Quality Standards, Red River and Red Lake River (39)	EPA Criteria in Drinking Water (36) (37)
Physical				
Color (units)	75	15	15	15
Turbidity (NTU)	--	10	25	1 (monthly average)
Total Dissolved Solids	500	500	500	500
Inorganic Chemical				
Arsenic (mg/1)	0.10	0.05	.01	0.05
Barium (mg/1)	1.0	1.0	1.0	1.0
Cadmium (mg/1)	.01	.01	.01	.01
Chromium (mg/1)	.05	.05	1.0	.05
Chloride (mg/1)	250	100	250	250
Copper (mg/1)	1.0	.05	.20	1.0
Lead (mg/1)	.05	.05	.05	.05
Manganese (mg/1)	.05	--	.05	.05
Mercury (mg/1)	.002	.002	--	.002
Nitrate Nitrogen (mg/1 as N)	10	1.0	45	10
Selenium (mg/1)	.01	.01	trace	.01
Silver (mg/1)	--	--	.05	.05
Sulfate (mg/1)	250	250	250	250
Zinc (mg/1)	5	1.0	1.0	5
Ammonia (mg/1)	0.5	.02	2.0	--
Biological				
Total Coliform	20,000/100 ml	--	--	1/100 ml (monthly average)
Fecal Coliform	2,000/100 ml	200/100 ml	250/100 ml	

[1]Represent maximum values acceptable.

Assessing the adequacy of treatment and storage for fire fighting is done below for the year 1990:

	Grand Forks (mgd)	East Grand Forks (mgd)
Maximum daily demand plus fire flow	22.5	14.7
Available from treatment plant	12.0	3.0
Available from storage (8-hour)	37.2	12.3
Excess flow capacity	26.7	0.6

Maximum daily demand from table 9 for the year 1990 is 10.97 mgd for Grand Forks and 3.27 mgd for East Grand Forks. The maximum daily demand rates plus the fire flow rates are added to obtain figures in the first line. The storage capacities for Grand Forks and East Grand Forks are 12.4 and 4.1 million gallons, respectively. Therefore, for an 8-hour period, water can be withdrawn from storage at a rate of 37.2 mgd and 12.3 mgd, respectively, if reservoirs are full at the time the fire fighting demand occurs. This rate plus the treatment plant capacity are added together and the maximum daily demand plus fire flow is subtracted to obtain the excess flow capacity.

Therefore, the existing treatment and storage system is judged adequate for the immediate future. The excess capacity available can reduce the design capacity of water treatment plants neede(to adequately meet the needs of the study area.

ADEQUACY OF WATER TRANSMISSION LINES

The major transmission line to the Air Force Base, although experiencing problems in the past, appears to be adequate especially with the ongoing replacement and cathodic protection program (31).

Problems in raw water transmission and treated water transmission lines for Grand Forks (25) and for East Grand Forks (29) have been identified and corrective programs initiated. Size and capacity evaluations internal to the distribution system are beyond the scope of this report.

WATER SUPPLY AND TREATMENT NEEDS

The existing water treatment and storage system appears to be adequate to meet the needs of the study area through at least 1985 based on the projected demands and evaluation criteria presented in prior sections. The major problem identified for the study area is the inadequacy of water supply sources to satisfy existing or future needs during low flow. Possible solutions include various combinations of: Garrison Diversion Unit flows, off-channel storage of surface water flows, groundwater, water reuse, reduced water use, and increased flows from the Red Lakes. Use of some of these solutions will involve arrangements with institutions outside the study area.

The existing water supply, treatment, and distribution system should prove adequate to meet the 15-year needs of the study area except during extreme low river flows that could occur during that period or a change in water treatment requirements.

WATER SUPPLY ALTERNATIVE FORMULATION

GENERAL

Prior sections have presented information to define the existing water supply systems in the study area and project problems and needs based on future water supply demands. This section presents information necessary to formulate alternative means to solve identified problems.

GENERAL METHODOLOGY

Water supply sources judged to be viable means of providing water to the study area are:

1. Surface water - The Red River of the North and the Red Lake River.

2. Groundwater - Either the local Dakota aquifer or the Elk Valley alluvial aquifer.

3. Water reuse.

Additional groundwater investigations may disclose alluvial aquifers closer to the urban area, but this was judged unlikely from known information.

Each supply source requires specific treatment. Quantity needs can be met in alternative ways as indicated below:

Supply	Quantity	Treatment type
Red River of the North/ Red Lake River	Garrison Diversion Off-channel storage On-channel storage	Surface water
Elk Valley Aquifer	Sole source Supplement to rivers	Softening
Dakota Aquifer	Sole source Supplement to river	Desalination
Water reuse	Supplement to river	Advanced reuse system

Five service groups were identified: Grand Forks, Air Force Base-Emerado area, East Grand Forks, self-supplied industries, and rural system users. Rural systems include Manvel, Thompson, and all other rural study area population. Alternatives consist of combinations of service groups with alternative supply sources and associated treatment.

Alternatives are developed from consideration of many other factors associated with each service group:

1. Projected water demands.
2. Condition of existing water distribution and treatment facilities.
3. Proximity to other service areas.
4. Water quality characteristics of the potential supply source.

Each of these factors has a significant influence on the feasibility of combining service areas by using a regional facility as opposed to retaining separate systems.

Projected water demands by service group are summarized in table 11.

Table 11 - Projections for water demand

	Design Maximum Day Flow (MGD)					
Year	Grand Forks and Air Force Base	East Grand Forks	Self-Supplied Industries[1]	Rural	Emerado[2]	Total
1976	9.1	2.5	2.0	0.4	0.1	14.1
2000	12.6	3.7	2.0	0.7	0.2	19.2
2030	18.6	5.2	2.0	0.9	0.3	27.0

[1]Consists of surface water use by American Crystal Sugar (1.7 MGD) and Burlington Industrial area (0.3 MGD).

[2]Based on 150 gpcd maximum daily demand.

Water supply and treatment alternatives are presented in the following section. Background information and methodologies of analysis are described in this section.

WATER QUALITY CONSIDERATIONS

Treatment schematics were developed for each source. They are shown on figure 11 and are discussed in the following paragraphs.

Surface Water

Surface waters will generally require treatment similar to the present water treatment in Grand Forks and East Grand Forks as shown on figure 9. In February 1978, the Environmental Protection Agency issued proposed regulations for the control of organic contaminants in drinking water. The regulations propose the use of granular activated carbon treatment for cities with a population over 75,000. This proposed regulation has caused considerable controversy in the water treatment field, primarily over the necessity and the economic impact of such a requirement. The deadline for public comment on the proposed regulations extends to 31 August 1978. It is hoped that this matter will be resolved so that it can be evaluated in stage 3 of this study. The advanced surface water treatment plant on figure 11 reflects the requirements of this proposed regulation.

Little information has been made available concerning the water treatment capabilities of certain self-supplied industrial water users. Untreated surface water is adequate for certain cooling and industrial washing functions.

Local Aquifers

The local aquifers (Grand Forks, Dakota) are high in total dissolved solids (2,000 to 3,000 and up to about 14,000 mg/l). The water from these sources would be treated to reduce the total dissolved solids levels to less than 500 mg/l. This would generally require desalination. A treatment system based on reverse osmosis desalination of the Dakota aquifer is proposed. The Grand Forks aquifer is limited in capacity to meet urban demands.

Alluvial Aquifers

Of the alluvial aquifers in the study area, the Elk Valley is the most extensive and, therefore, the most suitable from a quantity standpoint. This aquifer has a better quality of water than local bedrock aquifers. The water from this aquifer is hard (about 400 mg/l as calcium carbonate); therefore, it would be desirable to soften the water prior to public use.

Elk Valley water would be easier to treat than Red River and Red Lake River water because of the lack of suspended solids, color, high coliform counts, etc. Another factor tending to make treatment easier is the consistency of the quality of the raw water source. The pH, hardness, alkalinity, etc., would not be expected to fluctuate as much for the groundwater source as they do for a surface water source. Generally, the chemical doses would be adjusted for flow variation and not because of raw water chemical variations. Less operator time would be required to monitor the plant's operation.

Use of this aquifer as a supply source would also mean that advanced surface water treatment would not be required for the urban area.

Wastewater Reuse

The water in the wastewater treatment lagoons could be used to supplement surface water supplies at low-flow periods. An advanced water reuse facility based on a pilot plant conceptually designed for the board of water commissioners of Denver, Colorado, was used as the basis for the treatment system for water reuse alternatives.

WATER QUANTITY CONSIDERATIONS

The objective of the urban study is to develop alternatives that, when implemented, will supply an adequate quality and quantity of water to meet urban needs. Prior sections have indicated that the surface water resources at low-flow periods cannot provide an adequate quantity

of water to the entire urban area. Of the various alternatives (purchase, new reservoirs, etc.) referred to previously, the following options are judged feasible to supplement or replace surface water as a water supply source:

1. Garrison Diversion Unit.
2. Off-channel storage.
3. In-channel storage.
4. Water reuse.
5. Use of groundwater.

In addition, water demands can be reduced by adopting water conservation and water recycle systems. Each of these alternative sources is discussed in the following paragraphs.

Garrison Diversion Unit

The Garrison Diversion Unit would provide about 45 cfs of supplemental flow to the Red River at Grand Forks at low flow. This quantity of water is in excess of future urban demands and would require essentially no change in supply sources and treatment. The implementation of this project is in question, but unless, or until, a firm decision is made to halt the project it remains a viable option.

Off-Channel Storage

One option to supplement existing surface water sources would involve off-channel storage reservoirs. Basically, facilities are constructed to divert water from the rivers during high river flows to storage facilities. The stored water is used to supplement or replace river water as a supply source during low river flows.

The construction of off-channel storage reservoirs would involve major commitments of land. Alternatively, old lake oxbows, the wastewater treatment lagoons if abandoned as part of wastewater facilities planning decisions, or expensive underground storage facilities would be used to provide storage volumes needed.

The design capacity of the off-channel storage reservoirs is a function of the reliability desired by surface water users in the study area. Because of the severe economic consequences of water shortages in the study area, reliability to meet demands during 30-day, 50-year low flows in the rivers is suggested for the study area if river water is the sole source of meeting future urban needs.

An analysis considering consumptive uses, downstream water demands, assumed channel losses, and evaporation from off-channel storage reservoirs is necessary to define off-channel storage needs. The scope of this report does not allow for collection of extensive data concerning the monthly consumption by upstream water users and the monthly water demands of the downstream water users. Therefore, the 1976 monthly consumptive uses on the Red Lake River and Red River shown in tables 2 and 3, respectively, were used to compute monthly consumption rates as percentages of the average annual water demands. It is assumed that during severe droughts, irrigation would not be allowed by regulatory agencies; therefore, consumptive uses for irrigation are not considered. Monthly consumptive use (excluding irrigation) as a percent of upstream water withdrawals for 1976 are shown in table 12. Future monthly water use patterns for Grand Forks and East Grand Forks are assumed to be the same as shown on figure 7. The future water consumption for the East Grand Forks American Crystal Sugar plant and Burlington Industrial area was assumed to be distributed throughout the year as it was in 1976.

The low-flow frequencies used in this analysis were average monthly 20- and 50-year. Use of monthly variations in low flow are considered sufficiently accurate to calculate storage requirements. The 20- and 50-year low stream flows by month for the Red River below Grand Forks are shown in table 12. The amount of channel losses between Grand Forks

Table 12 - Data used in off-channel storage calculations

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Upstream consumptive uses as percent of annual average river withdrawals:[1]												
Red Lake River	72	66	48	31	27	31	33	31	60	69	67	72
Red River	64	57	54	4	-37[2]	4	51	63	28	-11[2]	-23[2]	26
Industrial surface water withdrawals within the study area as a percent of average annual demands	145	88	57	46	37	18	---	278	115	287	91	38
Monthly 50-year recurrence low flows, cfs (46)	31	30	115	975	590	279	138	46	33	33	63	37
Monthly 20-year recurrence low flows, cfs (46)	66	64	201	1,416	834	486	250	100	81	82	124	79

[1] Irrigation withdrawals and the associated consumptive uses are omitted from this number.

[2] Negative numbers mean that more water was discharged to the river than was withdrawn (probably lagoon discharges were high during these months).

Source: Stanley Consultants

and Drayton, North Dakota, is not known; but it is expected to be small because the 7-day, 50-year low-flow projections for the Red River are about 19 cfs at both municipalities. For this analysis, it was assumed that, in addition to downstream municipal demands, an additional 5 cfs would be allowed to pass Grand Forks and East Grand Forks for water quality purposes and limited channel losses and to meet Canadian municipal demands from the United States-Canadian border to Lake Winnipeg. It was assumed that downstream industries would have to use off-channel storage or some other water source to meet their water needs during extreme low flows as will be necessary at Grand Forks and East Grand Forks.

Projected water demands for upstream and downstream surface water users are shown in table 13. The estimated off-channel storage volumes (not including the 1,900 acre-feet of in-channel storage available) needed to meet the projected water demands of the study area for the years 2000 and 2030 and for the 20- and 50-year monthly low river flows are shown below:

Low-flow frequency	Study year 2000 (ac-ft)	Study year 2030 (ac-ft)
20-year	0	1,500
50-year	6,000	14,000

Off-channel storage facilities could be constructed in one location for all the municipal and industrial surface water users in the study area or each water user could construct its own off-channel storage pumping station and reservoir. For the 50-year flow situation, the estimated total volumes of off-channel storage needed to be allocated to each major water user in the study area are as follows:

	Study year 2000 (ac-ft)	Study year 2030 (ac-ft)
Grand Forks/Air Force Base	3,600	8,800
East Grand Forks	1,000	2,500
American Crystal Sugar	800	2,000
Burlington Industrial	100	200
Rural Systems	500	500

These storage volumes were calculated based on 10-foot deep reservoirs. Shallower reservoirs would require larger total volumes because of the larger evaporating surface; the converse is true for deeper reservoirs.

One major difficulty with off-channel storage lagoons in the study area would be the problem of winter freezing which would require specific design considerations.

Whether existing river intakes and associated pumping facilities could be used for transporting water from the river to the storage reservoirs depends on the location of a proposed reservoir and the condition of the intakes and pumps.

In-Channel Storage

The existing dam at Grand Forks creates a pool of water that can be used to meet urban demands at low flow. The estimated existing storage is 2,400 acre-feet. In a dry year, about 500 acre-feet would be lost to evaporation for a total available storage of about 1,900 acre-feet. Dam modifications would be needed to allow continued passage of water to downstream water users. Because of the deteriorating condition of the present dam, major repairs or replacement is being proposed. Approximately 250 acre-feet of storage would be added for each foot of increased dam height. The approximately 1,900 acre-feet available during drought conditions would give 31 days of supply at projected average day urban water demands of 31 cfs in the year 2030. The storage volume available could be used to supplement the off-channel storage reservoirs or could be used to reduce the design capacity.

If the existing dam is not repaired or replaced, reliance on it to provide in-channel storage is questionable. Additional investigation may be warranted on the question of whether to repair or replace the dam if alternative water supply sources are used to meet urban demands.

Table 13 - Municipal and industrial water consumption upstream and downstream of the study area

	Current[1]		2000[2]		2020[1]		2030[2]	
	Municipal (MGD)	Other (MGD)	Municipal (MGD)	Other (MGD)	Municipal (MGD)	Other (MGD)	Municipal (MGD)	Othe (MGI
Upstream Surface Water Users								
Red River								
Breckenridge	0.50				1.09			
Wahpeton	0.7				1.78			
American Crystal Sugar		1.0				1.0		
Fargo	12.3				19.20			
Moorhead	3.6				9.09			
American Crystal Sugar		0.8				1.0		
Casselton	0.10				0.3			
Mayville	0.25				0.58			
Valley City	1.08				1.90			
Britton	0.06				0.08			
West Fargo[3]	0.35				1.4			
Other[4]		2.22				2.22		
TOTAL	18.9	4.0	27.9	4.1	35.4	4.2	39.2	4.:
Red Lake River								
Crookston	1.0				1.55			
American Crystal Sugar		1.4				1.4		
Thief River Falls	1.0				1.56			
Other Municipal[5]	0.22				0.33			
Other[4]		0.7				0.7		
TOTAL	2.2	2.1	2.9	2.1	3.4	2.1	3.7	2.:
TOTAL UPSTREAM CONSUMPTION	21.2	6.1	30.8	6.2	38.8	6.3	42.9	6.:

Table 13 (cont)

	Current[1]		2000[2]		2020[1]		2030[2]	
	Municipal (MGD)	Other (MGD)	Municipal (MGD)	Other (MGD)	Municipal (MGD)	Other (MGD)	Municipal (MGD)	Other (MGD)
Downstream Surface Water Users								
Red River Mainstem								
Drayton	0.25				0.25			
American Crystal Sugar		9.00				9.0[6]		
TOTAL DOWNSTREAM	0.25	9.00	0.25	9.0	0.25	9.0	0.25	9.0
CONSUMPTION	0.25	9.00	0.25	9.0	0.25	9.0	0.25	9.0

[1] Current and 2020 water demand projections were taken from reference (8) except where noted in other footnotes in this table.

[2] Future water demand projections for this analysis assume a steady uniform rate of increase from current levels to 2020 and beyond that to 2030.

[3] West Fargo currently uses a groundwater aquifer as a water source. This aquifer has had serious declines in the water table level. Perhaps in the future they will need to use a surface water source.

[4] Primarily livestock watering. For the sake of this analysis, it is assumed that these surface water withdrawals will not substantially increase in the future.

[5] The flow for other municipal withdrawals on the Red Lake River for the "current" column was taken from table 2. The 2020 projection assumes that these demands will increase by the same proportion as the flows for Crookston and Thief River Falls.

[6] Officials of American Crystal Sugar have stated that they do not expect increases in water consumption in the future because they expect more efficient water use in the future (27).

Water Reuse

The water stored in the wastewater lagoons in the study area could be used to supply water to urban water users during low river flows if the surface water treatment facilities are upgraded as shown on figure 11. During December through February and August, for the 50-year low-flow situation, most of the low flow in the river would be used and not returned immediately by upstream users. Therefore, during these months, all the water demands by surface water users would have to be met by other sources. If Grand Forks and East Grand Forks switch from lagoon to mechanical wastewater treatment plants, water reuse for water supply would not provide sufficient quantities of water during the 50-year low-flow period to the cities because of system water losses. If upstream cities and industries switch from lagoons to mechanical wastewater treatment plants, however, there may be enough water in the river during the 50-year low-flow situation to meet study area water demands.

The capacities of the additional treatment processes to convert the surface water treatment plant for reuse of lagoon wastewater during the 50-year low-flow situation for the years 2000 and 2030 are shown below:

Study year	Plant capacity (mgd)	Available wastewater (ac-ft)
2000	16	6,250
2030	22	8,500

If the wastewater is continually recycled through the lagoons, the total dissolved solids level may increase to a level where desalination may have to be included.

The wastewater for the study area could also be used indirectly as a water source by using it for groundwater recharge for local aquifers. This would occur to some extent if land application of wastewater is adopted as a wastewater treatment alternative. The wastewater is higher in total dissolved solids than is desirable for drinking water but is

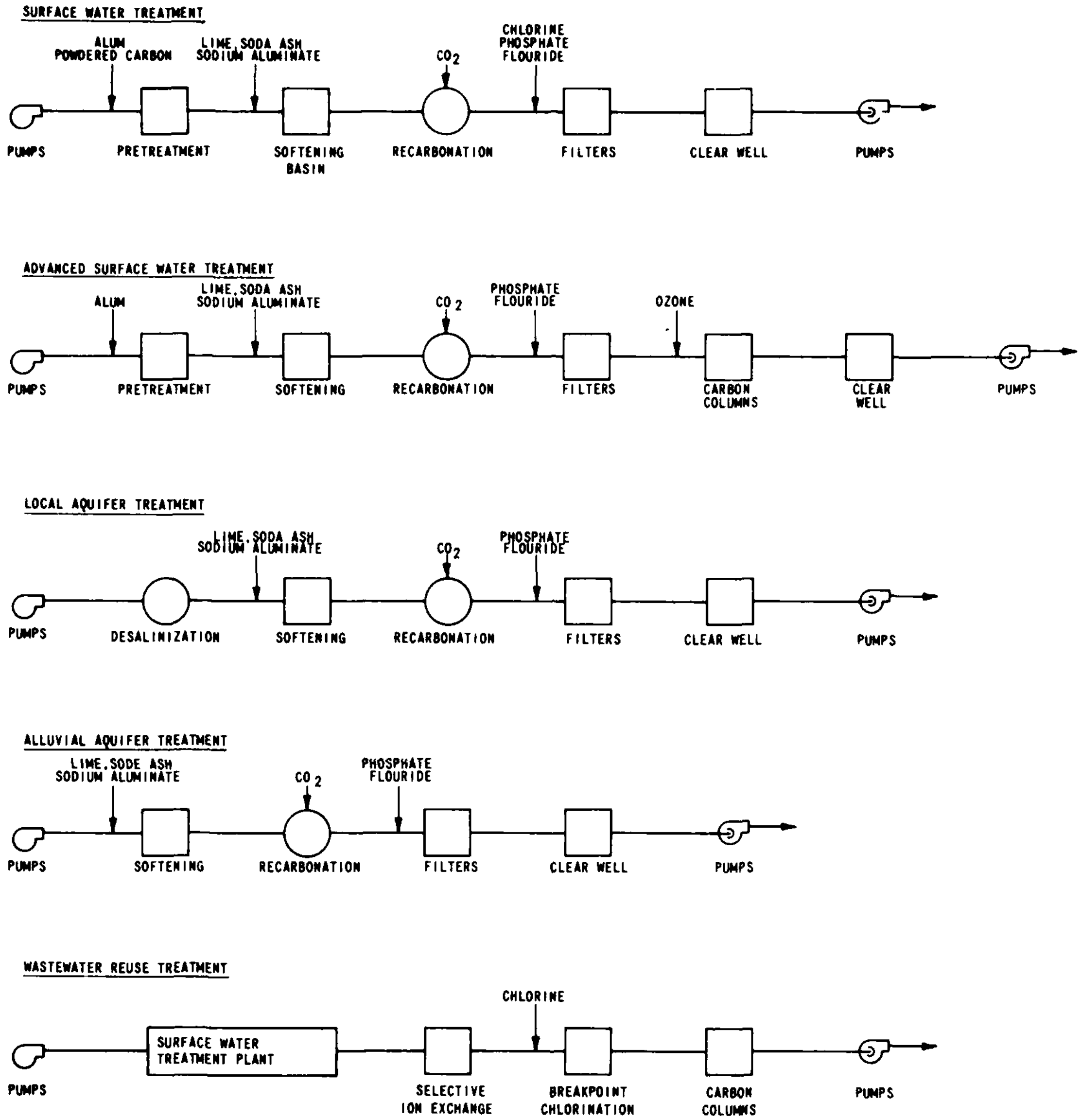


Figure 11 - Water Treatment Schematics

lower in total dissolved solids than the local aquifers. Therefore, groundwater recharge would be expected to slightly reduce the total dissolved solids levels in the aquifers. However, desalination of local groundwater would still be required.

Groundwater Sources

Two groundwater sources are considered: a local bedrock aquifer and the Elk Valley aquifer. Either source can be used as the sole supply to the study area or as a supplement to river sources.

Use of water from the Dakota aquifer as a supplemental supply source to the river supply would require the following desalination plant sizes to meet the study area demands for 2000 and 2030 during the 50-year low river flows:

Study year	Desalination plant size
2000	16 mgd
2030	27 mgd

To meet the year 2000 peak day demands, local wells and what river water is available would be used. If local wells are the only supply source for the study area, the size of plant needed for the year 2000 would be about 19 mgd. During the 50-year low river flow situation for 2030, it is estimated that peak day demands would have to be met entirely by a supplemental source because of increases in upstream use. Therefore, the size of a desalination plant for 2030 would be the same if local wells are used as the only source of supply or a supplemental supply to the river sources.

If Elk Valley wells are used as a supply source to the study area, the existing treatment facilities in Grand Forks and East Grand Forks could be used to soften the water. The facilities would be expanded as needed.

The treatment plant sizes needed to meet 2000 and 2030 study area demands are 19 mgd and 27 mgd, respectively. A pair of 30-inch water lines about 32 miles long could be used to carry the water from the well field to Grand Forks' and East Grand Forks' water treatment plants. Alternatively, surface canals could be used to transport the water, but freezing problems may limit the practicality of this option.

If the entire study area uses a groundwater source for supply, there would not be a need for off-channel storage reservoirs. With a large groundwater supply source, there is greater reliability of continued adequate supply during droughts than there is for the river supply sources at Grand Forks and East Grand Forks.

Local or regional aquifers could be used to supplement available surface water supplies. A water transmission line that could serve the Air Force Base from groundwater sources would solve some dependability problems. If a sufficient supply were available, the existing line from Grand Forks to the Air Force Base could be used to transmit water to Grand Forks during droughts. A branch line to Emerado would increase the reliability of that city's supply source by providing access to this supplementary supply.

Use of local wells would require considerably less energy to pump water from the wells to the treatment plant and the major users. Capital costs for pipeline installation would be considerably less for these wells than for wells in the Elk Valley aquifer.

Water Use Reduction

Reduction of water demands reduces water costs and also expenditures for wastewater treatment. Water consumption can be reduced by a number of measures:

1. Adopting water conservation practices.
2. Changing plumbing codes to require installation of water-saving devices.

3. Metering water consumption and charging for actual consumption.
4. Using water-saving devices such as faucet aerators, recycle toilets, reduced pressure shower heads, etc.
5. Using "gray water" (laundry water, wash basin water, shower water, kitchen sink water, etc.) for the flushing of toilets.

Toilets normally use 5 to 6 gallons per flush; however, water-saving toilets that use 3.5 gallons per flush can be purchased. Double flush toilets are manufactured that use about 3 gallons for a solid discharge and the flush lever can be switched the other direction to use half as much water to flush a liquid discharge. Major water using industries in the study area can significantly reduce future water consumption by practicing water conservation measures and by reusing process wastewater where higher quality water is not needed.

The design capacities needed to treat water from the alternative sources could be reduced if extensive water use reduction options are implemented. The nature of water users in the area, the ongoing water use reduction programs of the major industries in the study area as reflected in previous projections, and aesthetic considerations of urban greenery indicate that water use reduction programs may not have the potential to reduce urban demands significantly. Water use reduction options should be encouraged, but are not relied on in analyses used in this report to reduce demand.

ECONOMIC ANALYSIS OF ALTERNATIVES

The economic analysis of the alternatives was conducted for the entire study period which ends in 2030. Construction or capital costs (including replacement costs) and operation and maintenance costs are presented as well as equivalent annual costs. Capital costs are based on the required design capacity for water treatment and supply facilities (based on maximum daily demands) and operation and maintenance costs are based on the average daily demands. Future construction costs and salvage values were converted to present worth amounts and then to annual costs. The interest rate used in this analysis is 7 percent. The design life used for the treatment

plants was 25 years; plants are replaced at the end of the 25-year period. The design life used for pipelines, wells, and off-channel reservoirs was 50 years.

Historical cost information for surface water treatment for East Grand Forks (29) and Grand Forks (50) was updated and used to calculate the costs of future surface water treatment for these cities. Construction and operation and maintenance cost curves used to estimate costs of desalination, advanced surface water treatment, off-channel storage, and water reuse treatment are included in Attachment B. For the water reuse treatment scheme, the costs for the processes in the treatment plants now used by Grand Forks and East Grand Forks were assumed to be the same as costs for surface water treatment. The costs of pumping wastewater to the reuse plant, carbon adsorption, ballast pond storage, selective ion exchange, and control building and laboratory facilities were added to arrive at total water reuse costs. The cost of activated carbon and ozonation treatment was added to the surface water treatment curve to estimate the cost of advanced surface water treatment. The costs for piping and well construction used in the economic analysis are shown in table 14.

Table 14 - Piping and well costs

Item	Size	Cost
Pipe	12-inch	$28.50/L.F.
	20-inch	$39.00/L.F.
	24-inch	$40.00/L.F.
	30-inch	$65.00/L.F.
Well	500 gpm bedrock aquifer	$12,000/ea.
	375 gpm alluvial aquifer	$5,000/ea.

The cost of Garrison Diversion water was taken as $50/acre-foot used.

WATER SUPPLY AND TREATMENT ALTERNATIVES

GENERAL

This section develops water supply and treatment alternatives for the service groups identified in the previous section. The impact of the alternatives is presented in the following section.

RURAL WATER ASSOCIATIONS

The Agassiz Water Users Association and the Grand Forks-Traill Water Users, Inc., have wells in the Inkster and Elk Valley aquifers, respectively. These associations should have water of good quality (although fairly hard) and sufficient quantities from these aquifers for the study period. The adequacy of the water supply source for the Marshall and Polk Rural Water System has not been determined. Treatment of rural system waters consists mainly of home softeners.

The rural water systems have had a positive economic impact on the study area. A recent study (47) indicates that because of the installation of the Grand Forks-Traill Rural Water Association system, $5.4 million were spent in and near this water service area. The rural water systems have improved the quality of water consumed by many rural residents and have increased the reliability of water supply to these rural residents during dry years. The Grand Forks-Traill water system has stimulated some home construction within the service area (47). Members of this association have purchased more water-using appliances than nonusers which spurs local municipal economies.

Many rural residences have been constructed outside of the area over which Grand Forks has zoning or subdivision control. Prime farmland is being taken out of production causing an urban sprawl situation. Fire protection is more difficult to provide to such areas. The septic tanks and drain fields in these areas, if not constructed properly, may pose a health problem. Housing development outside the city's sphere of influence may have substandard streets

and water mains too small to be compatible with the city's water mains. Because of the small mains, it may be hard to maintain sufficient water pressure and water flows to end-of-the-line users if the city would ever annex areas that are now served by rural water system.

Three alternatives were explored for the rural water associations as follows:

1. Rural Systems Alternative A - Continued use of existing supply, treatment, and distribution system with expansions as necessary to accommodate new users.
2. Rural Systems Alternative B - Same as A except home softeners are added to all residences to provide a softened water to users.
3. Rural Systems Alternative C - The systems would continue to control the distribution system, but water would be supplied and treated with a regional system.

Each of these options is described further in the following paragraphs.

Rural Systems Alternative A

Existing and projected users and water demands for the rural system users in the study area are provided below:

	Present	2005	2030
Population	3,670	6,660	9,227
Homes served	1,225	2,220	3,076
Design flow (mgd)	0.37	0.67	0.92

Capital cost of the system is financed by a connection charge estimated at $325 per home. System operating and maintenance cost is estimated at $450/home/year. It was assumed that $50/home/year of this cost was associated with supply and treatment costs.

Rural Systems Alternative B

Softened water can also be supplied in the area by using home water softeners. For this option, home softeners were estimated to cost $300 installed, with annual costs of $50/unit for maintenance. The units were assumed to have a life of 10 years.

Rural Systems Alternative C

If rural systems were to tie into a regional system, the advantage would be softened water. Softened water could also be supplied to rural residences by interconnecting with a regional system. The equivalent of 10 miles of 8-inch pipe was assumed necessary to connect each rural system to a regional facility. If the rural systems were to join a regional system, they would also have to pay a proportional share of water supply and treatment costs of the regional supply and treatment. These costs were estimated at $400,000/mgd capacity for operation and maintenance.

Summary

Capital, operating and maintenance, replacement, and equivalent annual costs of these options are provided below.

	Rural systems		
	Alternative A	Alternative B	Alternative C
Capital costs ($)	12,000	379,000	3,500,000
O&M ($/yr)	760,000	844,000	750,000
Replacement ($)	154,000	695,000	190,000
Equivalent annual cost ($/yr)	772,000	922,000	1,017,000

GRAND FORKS

The existing surface water treatment capacity at Grand Forks is 12.0 mgd. The system currently serves the city's needs and supplies additional water to the Grand Forks Air Force Base. The only known noncity water supply in Grand Forks is water used by Pillsbury Company (0.2 mgd) and cooling water withdrawn from and returned to the Red River by Minnkota Power Cooperative (nonconsumptive use).

In developing alternatives, it was assumed that Grand Forks would continue to supply water to the Air Force Base. Increasing the reliability of supply to the Air Base is discussed under specific options for the base. Several alternatives were developed for Grand Forks:

1. Grand Forks Alternative A - This alternative consists of the present treatment facility which is expanded in 1990 (design flow of 15.4 mgd) and replaced in 2015 (design flow of 20.8 mgd). The water supply source would be the Red River of the North supplemented with Garrison Diversion water.
2. Grand Forks Alternative B - This alternative is the same as Alternative A except advanced surface water treatment is added in 1980 (design flow 12.0 mgd) and similar treatment is added in subsequent expansions.
3. Grand Forks Alternative C - This alternative is the same as Alternative A except off-channel storage is used to supplement river supply.
4. Grand Forks Alternative D - This alternative is the same as Alternative C except advanced surface water treatment is used.
5. Grand Forks Alternative E - This alternative uses Elk Valley water as a sole source of supply to the cities (design capacity is such that the option is the same for sole source as well as a supplement to river water). The existing treatment facilities would be used (less powdered carbon addition) and expanded in 1990 and replaced in 2015.
6. Grand Forks Alternative F - This alternative would be similar to Alternative E except the Dakota aquifer would be used and desalination added now, in 1990, and in 2015 as the treatment system is expanded or replaced.
7. Grand Forks Alternative G - This alternative would reuse lagoon waste-water to supplement river water supply. The design capacity would be 20.8 mgd to serve through 2030.
8. Grand Forks Alternative H - This alternative uses the Red River of the North as a water supply with supplemental flow from both in-channel and off-channel storage. Treatment facility expansion would be the same as in Alternative A.

Each alternative is designed to supply an adequate quantity and quality of water to Grand Forks and the Air Force Base. The quantity supplied by river water sources is adequate for a 50-year low-flow event. Each alternative is further discussed in the following paragraphs.

Grand Forks Alternative A

The supply from Garrison through the Red River would require essentially no change in water intakes. The cost of the water is estimated at $50/acre-foot used. Costs are based on paying for Garrison water supplied whether it is used or not. Capital (total construction) costs listed are for new and replacement facilities for the required design capacity and O&M (operation and maintenance) costs are annual costs for the year shown and are based on average flows. Costs and facilities involved in this alternative are listed below.

		Cost ($)	Notes
1980	O&M Supply	415,000	Increases linearly to 2030 value
1980	O&M Treatment	1,202,000	Increases linearly to 2030 value
1990	Capital Cost	5,400,000	For 15.4-mgd plant
2015	Capital Cost	6,600,000	For 20.8-mgd plant
2030	O&M Supply	767,000	For 13.7-mgd supply
2030	O&M Treatment	2,035,000	For 13.7-mgd treatment
2030	Salvage	2,640,000	For plant built in 2015

Economic analysis of this alternative yields an equivalent annual cost of $2,151,000 of which $232,000 is allocated to the Air Force Base and $1,919,000 is allocated to Grand Forks.

Grand Forks Alternative B

Costs and facilities involved in this alternative are:

		Cost ($)	Notes
1980	O&M Supply	415,000	Increases linearly to 2030 value
1980	Capital Cost	4,200,000	Add carbon and ozone for 12.0 mgd
1980	O&M Treatment	1,310,000	Increases linearly to 2030 value
1990	Capital Cost	10,300,000	For 15.4-mgd plant
2015	Capital Cost	12,500,000	For 20.8-mgd plant
2030	O&M Supply	767,000	For 13.7-mgd supply
2030	O&M Treatment	2,200,000	For 13.7-mgd treatment
2030	Salvage	5,000,000	For plant built in 2015

The equivalent annual cost is $2,800,000, of which $326,000 is allocated to the Air Force Base.

Grand Forks Alternative C

This alternative uses off-channel storage to supplement Red River wat water. Costs and facilities included are:

		Cost ($)	Notes
1980	Capital Cost	3,094,000	Reservoir and land
1980	O&M Supply	56,000	Increases linearly to 2030 value
1980	O&M Treatment	1,203,000	Increases linearly to 2030 value
1990	Capital Cost	5,400,000	For 15.4-mgd plant
2005	Capital Cost	4,394,000	Reservoir and land
2015	Capital Cost	6,600,000	For 20.8-mgd plant
2030	O&M Supply	110,000	For 13.7-mgd supply
2030	O&M Treatment	2,035,000	For 13.7-mgd treatment
2030	Salvage	7,168,000	For reservoir, land, and treatment

Economic analysis of this alternative yields an equivalent annual cost of $1,989,000, of which $222,000 is allocated to the Air Force

Grand Forks Alternative D

Costs and facilities included are.

		Cost ($)	Notes
1980	Capital Cost	3,094,000	Reservoir and land
1980	O&M Supply	56,000	Increases linearly to 2030 value
1980	Capital Cost	4,200,000	Add carbon and ozone for 12.0 mgd
1980	O&M Treatment	1,310,000	Increases linearly to 2030 value
1990	Capital Cost	10,300,000	For 15.4-mgd plant
2005	Capital Cost	4,394,000	Reservoir and land
2015	Capital Cost	12,500,000	For 20.8-mgd plant
2030	O&M Supply	110,000	For 13.7-mgd supply
2030	O&M Treatment	2,200,000	For 13.7-mgd treatment
2030	Salvage	9,528,000	For reservoir, land, and treatment

This represents an equivalent annual cost of $2,631,000, with $315,000 allocated to the Air Force Base.

Grand Forks Alternative E

Use of the Elk Valley aquifer would require the construction of a well field and 32 miles of twin 24-inch lines to serve the needs of Grand Forks and the Air Force Base. An average well yield of 375 gpm based on 1,000-foot spacing is used for the well field. Facilities for water treatment are assumed to initially be the existing treatment plant. Subsequent new facilities may be located at the well field or elsewhere along the transmission line route. Costs and facilities included in this alternative are:

		Cost ($)	Notes
1980	Capital Cost	14,645,000	25 wells, well piping, transmission line
1980	Capital Cost	3,150,000	Land for well field and piping
1980	O&M Supply	97,000	Increases linearly to 2030 value
1980	O&M Treatment	1,202,000	Increases linearly to 2030 value
1990	Capital Cost	5,400,000	New plant, 15.4 mgd
2005	Capital Cost	625,000	Replace wells, add 10, add piping
2015	Capital Cost	6,600,000	New plant, 20.8 mgd
2030	O&M Supply	180,000	For 13.7-mgd flow
2030	O&M Treatment	1,832,000	For 13.7-mgd flow
2030	Salvage	5,790,000	Land and treatment system

The equivalent annual cost of this alternative is $3,006,000, with $342,000 allocated to the Air Force Base.

Grand Forks Alternative F

Use of the Dakota aquifer would require desalination as well as softening for treatment. An average well yield of 500 gpm is used in this option. Initially, the present water treatment system would be used, but the location may be changed in plants built at later dates. Costs and facilities included in this alternative include:

		Cost ($)	Notes
1980	Capital Cost	953,000	19 wells, well field, interconnects
1980	Capital Cost	2,100,000	Land for well field and piping
1980	Capital Cost	22,700,000	Desalination plant, 13.6 mgd

		Cost ($) (continued)	Notes (continued)
1980	O&M Supply	49,000	Increases linearly to 2030 value
1980	O&M Treatment	2,498,000	Increases linearly to 2030 value
1990	Capital Cost	5,400,000	Water treatment plant, 15.4 mgd
2005	Capital Cost	29,000,000	Desalination plant, 18.6 mgd
2005	Capital Cost	612,000	Replace wells, add 7, add piping
2015	Capital Cost	6,600,000	Water treatment plant - 20.8 mgd
2030	O&M Supply	91,000	For 20-mgd flow
2030	O&M Treatment	4,110,000	For 20-mgd flow
2030	Salvage	4,740,000	For land and plants

The equivalent annual cost of this alternative is $5,344,000, with $641,000 allocated to the Air Force Base.

Grand Forks Alternative G

This alternative would supplement surface water supply by reusing lagoon effluent at low river flows. Because of intermittent use, a 20.8-mgd plant is built initially. It was assumed that the facilities would be used the equivalent of 2 years prior to 2030. Facilities included in this option include:

		Cost ($)	Notes
1980	Capital Cost	15,300,000	Reuse plant and 5.5 miles 20" pipeline
1980	O&M Supply	149,000	Annual cost through 2030 of reuse
1980	O&M Treatment	1,202,000	Increase linearly to 2030 value
1990	Capital Cost	5,400,000	For 15.8-mgd plant
2015	Capital Cost	6,600,000	For 20.8-mgd plant
2030	O&M Treatment	2,035,000	For 13.7-mgd
2030	Salvage	2,640,000	For plant built in 2015

The equivalent annual cost of this alternative is $2,900,000, of which $334,000 is allocated to the Air Force Base.

Grand Forks Alternative H

This alternative uses in-channel storage available to reduce the capacity of off-channel storage required.

Thus, the 1980 capital cost for reservoir and land is reduced to $1,366,000, 2005 capital costs are reduced to $2,726,000, and salvage value is reduced to $4,362,000. All other costs are the same as those for Alternative C. The equivalent annual cost of this option is $1,933,000, of which $222,000 is allocated to the Air Force Base. With advanced surface water treatment, equivalent annual costs increase to $2,463,000, with $283,000 allocated to the Air Force Base.

Summary

Table 15 summarizes alternatives for Grand Forks and allocates costs to the city and the Air Force Base. On the basis of analysis, if advanced surface water treatment is not required in future years, a combination of in-channel and off-channel storage appears most cost effective. If advanced surface water treatment is required, then a supply from Elk Valley becomes more economically competitive with supplemented river supplies. Desalination of the Dakota aquifer supply or water reuse does not appear to be cost effective when compared to the other surface water treatment alternatives.

Table 15 - Grand Forks water supply and treatment alternatives

Alternative	Description	Equivalent annual cost ($1,000,000) Total	Grand Forks	Air Base
A	Garrison-Surface Water Treatment	2.151	1.919	0.232
B	Garrison-Advanced Surface Water Treatment	2.800	2.474	0.326
C	Off-Channel Storage-Surface Water Treatment	1.989	1.767	0.222
D	Off-Channel Storage-Advanced Surface Water Treatment	2.631	2.316	0.315
E	Elk Valley Aquifer Supply	3.006	2.664	0.342
F	Dakota Aquifer Supply	5.344	4.703	0.641
G	Lagoon Water Reuse-Surface	2.900	2.566	0.334
H_1	Off-Channel/In-Channel-Surface	1.933	1.711	0.222
H_2	Off-Channel/In-Channel-Advanced Surface	2.463	2.180	0.283

The Garrison alternatives are based on paying for Garrison water supplied whether it is used or not, which may be subject to negotiation.

SELF-SUPPLIED INDUSTRIES

Little information has been made available concerning the water treatment capabilities of the self-supplied surface water users. If they are to continue to process their own surface water, they should examine their projected water needs during extreme low river flows. If necessary, they may want to construct off-channel reservoirs or arrange to meet their water demands by alternate means. Industrial water users may reduce their water supply costs by making their plants more water efficient and by water reuse within their plants where possible. As mentioned earlier, American Crystal Sugar has stated it does not plan to increase its water consumption while increasing production output.

The cities could sell treated water to American Crystal Sugar, Burlington Industrial, Pillsbury, International Co-op, and any other industries. These industries would not have to operate and maintain their own treatment works. If all industries in the study area were to buy treated surface water from a single utility, the overall quality of the wastewater discharged to lagoons would probably be enhanced by eliminating the use of local well water high in total dissolved solids. The shortcomings of supplying a uniform quality of water to all industries are twofold:

1. Some of the industries may need a higher quality water than provided (this water would require extra treatment).
2. Some industries may not require as high a quality of water as would be produced by the utility (the extra cost of treating the water to a higher quality could be avoided).

The level of protection needed for industries could be different than city needs because the option of suspending operations during very low-flow periods may be more economical than providing for adequate water.

Two options were investigated for the self-supplied industries. Neither local nor alluvial aquifers were judged economical for the industries alone. Water reuse or recycle is possible, but would require more detailed analysis. If the cities switch to groundwater as a supply source, there should be sufficient water in the rivers to meet industrial demands.

Self-Supplied Industries Alternative A

This alternative would use river water to meet demands. It is assumed that present facilities are adequate to 1990 at which time they would be replaced with surface water treatment facilities. New facilities would be constructed in 2015 to meet the needs through 2030. Costs and facilities included are:

		Cost ($)	Notes
1980	O&M Treatment	400,000	Constant value to 2030
1990	Capital Cost	1,450,000	For 2.0-mgd plant
2015	Capital Cost	1,450,000	For 2.0-mgd plant
2030	Salvage	580,000	For 2015 plant

The equivalent cost of this alternative is $462,000.

Self-Supplied Industries Alternative B

This alternative would ensure adequate water at low river flow by adding off-channel storage reservoirs. Costs and facilities involved in addition to those in Alternative A are:

		Cost ($)	Notes
1980	Capital Cost	998,000	For reservoirs and land
1980	O&M	26,000	Increases linearly to 2030 value
2005	Capital Cost	1,376,000	For reservoirs and land
2030	O&M	32,000	For 2,200 acre-foot system
2030	Salvage	1,339,000	For reservoirs and land

The equivalent annual cost of these additions is $115,000 for a total alternative equivalent annual cost of $577,000.

These industries can also be supplied by the cities; this alternative is explored in subsequent joint options in this section.

EAST GRAND FORKS

The water treatment plant at East Grand Forks is considered capable of adequately treating 3 mgd. Perhaps with the aid of polymers and/or surface settling tubes placed in the clarifiers, the plant could adequately treat the 4 mgd that it can otherwise handle hydraulically. Considering projected water demands for East Grand Forks, the existing plant would have to be expanded or replaced in the mid-1980's. For planning purposes, it is assumed that the plant will be upgraded in the mid-1980's and replaced about 2005 to meet projected water demands to the end of the planning period. Several alternatives were investigated for East Grand Forks.

East Grand Forks Alternative A

This alternative would use surface water with no supplement. Adequate water would be available in the Red River (minimum 10 cfs or 6.5 mgd) to meet East Grand Forks' needs if Grand Forks switched to groundwater for a supply. Costs and facilities involved are:

		Cost ($)	Notes
1980	O&M Treatment	430,000	Increases linearly to 2030 value
1990	Capital Cost	700,000	Modify to handle 4.0 mgd
2005	Capital Cost	2,750,000	New plant for 5.2 mgd
2030	O&M Treatment	680,000	For 5.2-mgd flow

The equivalent annual cost of this option is $555,000.

East Grand Forks Alternative B

This alternative would add advanced surface water treatment facilities in 1980 and subsequent years. Costs and facilities involved are:

		Cost ($)	Notes
1980	Capital Cost	1,750,000	For 4.0-mgd carbon and ozone
1980	O&M Treatment	482,000	Increases linearly to 2030 value
1990	Capital Cost	700,000	Upgrade system to 4.0 mgd
2005	Capital Cost	4,800,000	New plant 5.2 mgd
2030	O&M Treatment	749,000	For 3.8-mgd flow

The equivalent annual cost of this alternative would be $638,000.

East Grand Forks Alternative C

This alternative would supplement surface water available with Garrison Diversion water. The equivalent annual cost of Garrison water is $186,000. Added to Alternative A, the total annual cost would be $741,000. Added to Alternative B, the total annual cost would be $824,000.

East Grand Forks Alternative D

This alternative would supplement surface water available from the Red River with off-channel storage and would not rely on Garrison Diversion water. Facilities included are:

		Cost ($)	Notes
1980	Capital Cost	1,090,000	Reservoir and land
1980	O&M Supply	27,000	Increases linearly to 2030 value
2005	Capital Cost	1,540,000	Reservoir and land
2030	O&M Supply	35,000	For 2,200 acre-feet
2030	Salvage	1,505,000	Reservoir and land

The equivalent annual cost of the supply supplement is $125,000, which can be added to costs in Alternative A and B to yield total system costs of $680,000 and $763,000, respectively. The cost of Alternative D may be reduced if in-channel storage is available.

Summary

Table 16 summarizes the costs of the various alternatives for East Grand Forks alone. Use of local bedrock or alluvial aquifers to supplement or replace surface water supplies was judged infeasible for East Grand Forks alone.

EMERADO/AIR FORCE BASE

Emerado is served by an 8-inch line approximately 8 miles long from the Elk Valley aquifer. For a backup supply, the city would extend a line to the Air Force Base system. This would require an 8-inch line approximately 2 miles long at a cost of $190,000. The supply system would deliver about 0.7 mgd less city peak demands of 0.3 mgd in 2030 or about 0.4 mgd to the Air Force Base in emergency conditions also.

Table 16 - East Grand Forks water supply and treatment alternatives

Alternative	Description	Equivalent annual cost ($1,000,000)
A	Surface water treatment	0.555
B	Advanced surface water treatment	0.638
C1	Garrison-surface water treatment	0.741
C2	Garrison-advanced surface water treatment	0.824
D1	Off-channel-surface water treatment	0.680
D2	Off-channel-advanced surface water treatment	0.763

The Air Force Base could, but is not likely to, supplement its city-supplied water by constructing a pipeline and well field. A system based on 17 miles of twin 12-inch lines and a well field of 1 acre (three wells) would have a capital cost of $5,206,000, and an equivalent annual cost of $392,000. If Emerado were added to the project, the capital cost would increase to $5,421,000 with an equivalent annual cost of $409,000 ($342,000 for Air Force Base, $67,000 for Emerado).

Water supplied under the above options has not included treatment. Treatment costs are estimated at $750,000/mgd capacity with an operating cost of $700/mgd.

Emerado/Air Force Base Alternative A

This alternative consists of supplying water to the Air Force Base from Grand Forks as costed in Grand Forks Alternative H. Emerado would continue to obtain water from its present system. The annual cost to the Air Force Base as developed in Grand Forks Alternative H is $222,000 for treated surface water and $283,000 for advanced surface water treatments. The operation and maintenance cost of the existing Emerado system is estimated to have an equivalent annual cost of $38,000.

Emerado/Air Force Base Alternative B

This alternative would supply a treated water to the Air Force Base by developing a well field in the Elk Valley aquifer. Costs and facilities included are:

		Cost ($)	Notes
1980	Capital Cost	5,206,000	Transmission line and well field
1980	Capital Cost	1,200,000	For 1.5-mgd plant
1980	O&M Supply	15,000	Constant to 2030
1980	O&M Treatment	281,000	Constant to 2030
2005	Capital Cost	1,200,000	For 1.5-mgd plant
2030	Salvage	7,000	Land

The equivalent annual cost of this alternative is $776,000 which clearly exceeds the cost of water from city sources. Increasing the system size to serve both Emerado and the Air Force Base would result in an equivalent annual cost of $884,000.

Summary

A separate water supply and treatment system for the Emerado/Air Force Base does not appear to be cost effective when compared to existing supply and treatment systems. The reliability of the systems can be increased somewhat by interconnecting the city and Air Force Base systems. The reliability can be greatly increased if Grand Forks or the urban area switches

to a groundwater system from the Elk Valley aquifer. The transmission line should be located so these users can be served. In future years, new water treatment facilities for the urban area could be located at the well field which would result in treated water being available from branch lines from the main transmission line.

JOINT SYSTEMS

Prior analyses have examined separate supply and treatment alternatives for individual service groups. The results indicate it is more cost-effective for the rural water associations to remain separate from systems serving the urban area, it is more cost effective for the Air Force Base to be served by Grand Forks than separately, and Emerado can increase reliability by interconnecting with the Air Force Base system.

If surface waters are to be used to meet future water demands, it may be desirable to have one water utility. An existing water line interconnects treated water storage tanks in Grand Forks and East Grand Forks. There are plans for construction of a line to connect the discharge lines from the Red Lake River intakes of both cities. If the entire urban area is to rely on the Grand Forks and East Grand Forks treatment plants, the plants would currently be near capacity and in need of expansion. To meet the 2000 and 2030 water demands, the treatment plant sizes would be 18 mgd and 26 mgd, respectively.

Grand Forks, East Grand Forks, and the industrial surface water users could initially continue to treat their own water. When the water demands of one of the cities reaches its treatment plant capacity, it could possibly buy water from the other. Likewise, one of the industries may at some time in the future find it more desirable to buy its water from a city rather than treat its own water.

If Grand Forks and East Grand Forks joined together to treat surface water, new or expanded treatment facilities would be necessary in about 1990. At that time, the treatment capacity could be increased to 20.1 mgd to provide treatment for the two cities (without the self-supplied industries) until 2015. At 2015, the treatment capacity for the two plants could be increased to enable the two cities to meet projected water demands for the next 25-year period.

Several alternatives are discussed in the following pages.

Joint Systems Alternative A

In this alternative, Grand Forks and East Grand Forks would develop a water supply source from the Elk Valley aquifer. The self-supplied industries would obtain their water from the Red Lake or Red River. The water treatment facilities of each city would be used until 1990 at which time a new regional water treatment plant would be constructed. This plant would be replaced in 2015. Facilities included are:

		Cost ($)	Notes
1980	Capital Cost	22,000,000	32 miles twin 30-inch lines
1980	Capital Cost	4,315,000	Well field and piping and land
1980	Capital Cost	171,000	3,000 feet twin 12" to East Grand Forks
1980	O&M Supply	188,000	Increase linearly to 2030 value
1980	O&M Treatment	430,000	East Grand Forks
1980	O&M Treatment	1,202,000	Grand Forks
1990	Capital Cost	6,700,000	For 20.1-mgd plant
2005	Capital Cost	1,770,000	Well field expansion
2015	Capital Cost	7,700,000	For 26.4-mgd plant
2030	O&M Supply	343,000	For 17.5-mgd flow
2030	O&M Treatment	680,000	East Grand Forks
2030	O&M Treatment	2,035,000	Grand Forks
2030	Salvage	7,080,000	For land and 2015 plant

The equivalent annual cost of these facilities is $4,066,000, which can be allocated as $2,862,000 to Grand Forks, $304,000 to the Air Force Base and $900,000 to East Grand Forks.

Joint Systems Alternative B

This alternative is similar to Alternative A except surface water supply is supplemented with Garrison Diversion unit water. The equivalent annual cost of this alternative is $2,885,000 with $1,968,000 allocated to Grand Forks, $659,000 to East Grand Forks, and $258,000 to the Air Force Base.

Joint Systems Alternative C

This alternative is similar to Alternative A except off-channel storage is used to supplement surface water supply. The equivalent annual cost of this alternative is $2,536,000, with $1,740,000 allocated to Grand Forks, $585,000 to East Grand Forks, and $211,000 to the Air Force Base.

The combined cost of Grand Forks Alternative C and East Grand Forks Alternative D1 is $2,669,000, indicating cost savings by regionalization.

Joint Systems Alternative D

If surface waters are continued to be used for a supply, it may be necessary to convert to advanced surface water treatment. This alternative considers such a conversion at each city's facilities in 1980 followed by a new joint treatment plant in 1990. River supply would be supplemented by off-channel storage. Self-supplied industries and rural system users would continue to use their own supply. Costs and facilities involved in this alternative are:

		Cost ($)	Notes
1980	Capital cost	3,800,000	Reservoir and land (4,200 acre-feet)
1980	Capitol cost	4,200,000	Add carbon and ozone at Grand Forks
1980	Capital cost	1,750,000	Add carbon and ozone at East Grand Forks
1980	O&M supply	69,000	Increases linearly to 2030 value
1980	O&M treatment	1,310,000	For Grand Forks
1980	O&M treatment	482,000	For East Grand Forks
1990	Capital cost	12,700,000	For 20.1-mgd plant
2005	Capital cost	5,400,000	Reservoir and land (6,200 acre-feet)
2015	Capital cost	14,800,000	For 26.4-mgd plant
2030	O&M supply	91,000	For 17.5-mgd system
2030	O&M treatment	2,949,000	For 17.5-mgd flow
2030	Salvage	11,350,000	For land, reservoir, and treatment

The equivalent annual cost of these facilities is $3,476,000 with $2,460,000 allocated to Grand Forks, $774,000 to East Grand Forks, and $242,000 to the Air Force Base.

Joint Systems Alternative E

This alternative is similar to Alternative D except Garrison Diversion unit water is used as the supply source. The equivalent annual cost of this option is $3,644,000 with $2,562,000 allocated to Grand Forks, $805,000 to East Grand Forks, and $277,000 to the Air Force Base.

Joint Systems Alternative F

This alternative would provide a water supply for all urban area users, Grand Forks, East Grand Forks, the Air Force Base, and the self-supplied industries. Supply would be from the Red River of the North supplemented by off-channel storage. Each system would operate separate treatment facilities until 1990 at which time a new regional treatment facility would be constructed.

This alternative would have an equivalent annual cost of $2,831,000 with $1,792,000 allocated to Grand Forks, $567,000 to East Grand Forks, $294,000 to self-supplied industries, and $178,000 to the Air Force Base.

Joint Systems Alternative G

This alternative is similar to Alternative F, except advanced surface water treatment is added. The equivalent annual cost of this alternative is $3,778,000.

Joint Systems Alternative H

This alternative makes use of in-channel storage to reduce the size of off-channel reservoirs. Surface water treatment is provided. The equivalent annual cost is $2,394,000.

Joint Systems Alternative I

This alternative is similar to Alternative H except advanced surface water treatment is provided. The equivalent annual cost is $3,262,000.

Summary

Table 17 summarizes the alternatives presented above.

STUDY AREA COST SUMMARY

This section has presented information on alternative water supply and treatment schemes for five major user groups. Water supply options were basically groundwater from the Elk Valley aquifer and river water from the Red Lake and Red Rivers supplemented by Garrison Diversion water or off-channel/in-channel storage. Where river water was used, the cost of advanced surface water treatment was investigated.

The separate and joint system alternatives can be combined in various ways to yield total study area options and costs. Table 18 presents these options in summary form. Figures 12 and 13 show major physical facilities to provide groundwater from the Elk Valley aquifer and off-channel storage reservoirs.

Table 17 - Water supply and treatment options - joint system

Alter-native	Description	Equivalent Annual Cost				
		Total	Grand Forks	East Grand Forks	Air Force Base	Industries[1]
A	Elk Valley Supply	$4,066,000	$2,862,000	$900,000	$ 304,000	($462,000)
B	Garrison Supply	2,885,000	1,968,000	659,000	258,000	(462,000)
C	Off-Channel Supply	2,536,000	1,740,000	585,000	211,000	(462,000)
D	Off-Channel-Advanced Treatment	3,476,000	2,460,000	774,000	242,000	(462,000)
E	Garrison-Advanced Treatment	3,644,000	2,562,000	805,000	277,000	(462,000)
F	Off-Channel-All Users	2,831,000	1,792,000	567,000	178,000	294,000
G	Off-Channel-All Users Advanced	3,778,000	2,431,000	746,000	231,000	370,000
H	Off-Channel/In-Channel-Surface	2,394,000	1,635,000	556,000	203,000	(462,000)
I	Off-Channel/In-Channel-Advanced	3,262,000	2,305,000	727,000	230,000	(462,000)

[1]Annual cost for industries shown in parentheses for Alternatives A, B, C, D, E, F, H, and I is the cost providing own water supply and treatment and is not included in the total costs. Annual cost for industries for Alternatives F and G are included in the total costs because the industries receive their water supply from these regional alternatives.

Table 18 - Total study area costs

Option	Alternatives[1]	Equivalent Annual Costs: Grand Forks	East Grand Forks	Air Force Base	Industries	Rural	Total
Garrison							
Surface	GF(A),EGF(C1),I(A),R(A)	$1,919,000	$741,000	$232,000	$462,000	$772,000	$4,126,000
Advanced	GF(B),EGF(C2),I(A),R(A)	2,474,000	824,000	326,000	462,000	772,000	4,858,000
Surface	JOINT(B),I(A),R(A)	1,968,000	659,000	258,000	462,000	772,000	4,119,000
Advanced	JOINT(E).I(A),R(A)	2,562,000	805,000	277,000	462,000	772,000	4,878,000
Off-Channel							
Surface	GF(C),EGF(D1),I(A),R(A)	1,767,000	680,000	222,000	462,000	772,000	3,903,000
Advanced	GF(D),EGF(D2),I(A),R(A)	2,316,000	763,000	315,000	462,000	772,000	4,628,000
Surface	JOINT(C),I(A),R(A)	1,740,000	585,000	211,000	462,000	772,000	3,770,000
Advanced	JOINT(D),I(A),R(A)	2,460,000	774,000	242,000	462,000	772,000	4,710,000
Surface	JOINT(F),R(A)	1,792,000	567,000	178,000	294,000	772,000	3,603,000
Advanced	JOINT(G),R(A)	2,431,000	746,000	231,000	370,000	772,000	4,550,000
Elk Valley							
Surface	GF(E),EGF(A),I(A),R(A)	2,664,000	555,000	342,000	462,000	772,000	4,795,000
Advanced	GF(E),EGF(B),I(A),R(A)	2,664,000	638,000	342,000	462,000	772,000	4,878,000
Surface	JOINT(A),I(A),R(A)	2,862,000	900,000	304,000	462,000	772,000	5,300,000
Off-Channel/In-Channel							
Surface	GF(H1),EGF(D1),I(A),R(A)	1,711,000	680,000	222,000	462,000	772,000	3,847,000
Advanced	GF(H2),EGF(D2),I(A),R(A)	2,180,000	763,000	283,000	462,000	772,000	4,460,000
Surface	JOINT(H),I(A),R(A)	1,635,000	556,000	203,000	462,000	772,000	3,628,000
Advanced	JOINT(I),I(A),R(A)	2,305,000	727,000	230,000	462,000	772,000	4,496,000

[1] Notations refer to Grand Forks (GF), East Grand Forks (EGF), Industries (I), and Rural Users (R). The alternatives used in each combination refer to the alternatives previously presented.

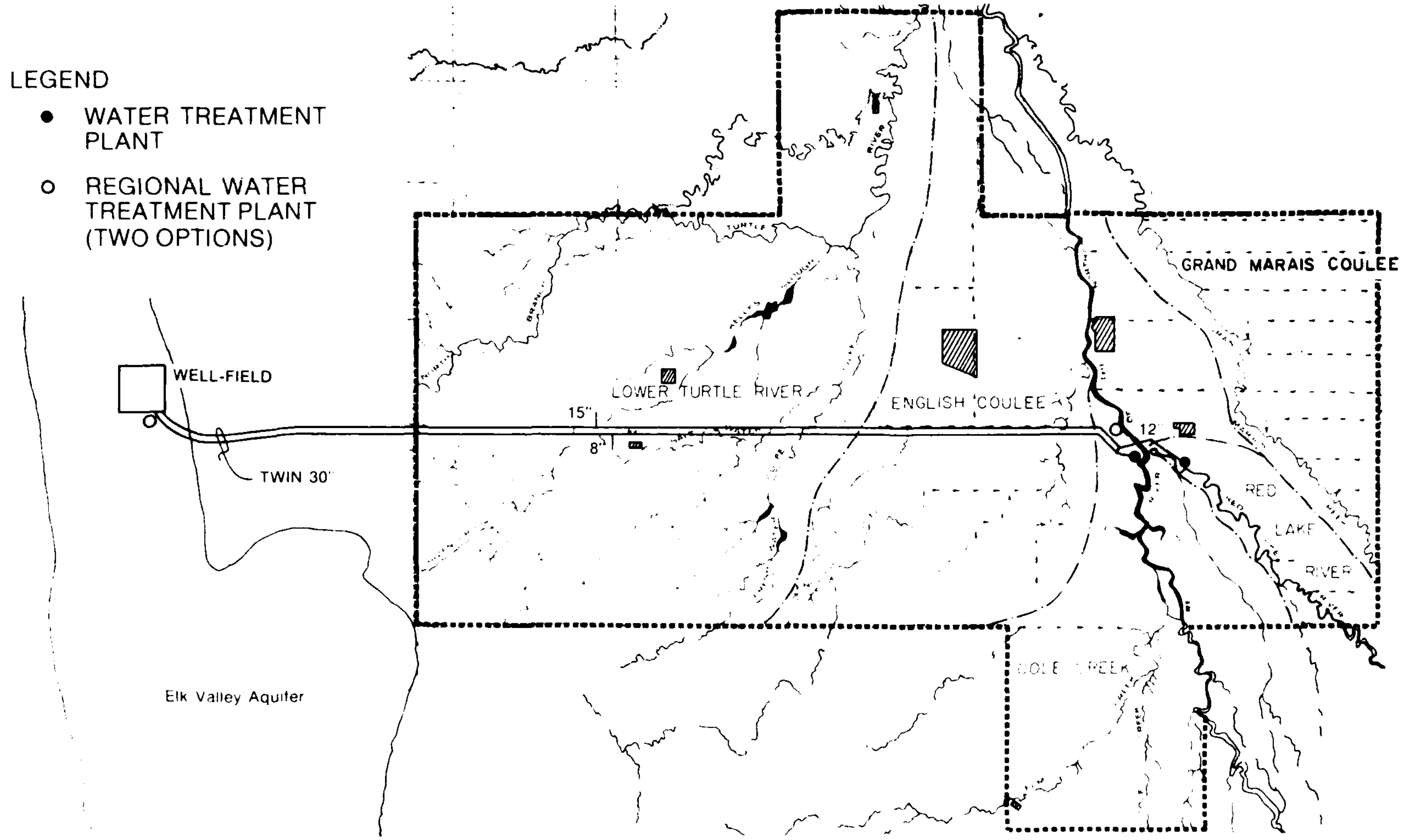


Figure 12 - Elk Valley Supply - Location of Major Facilities

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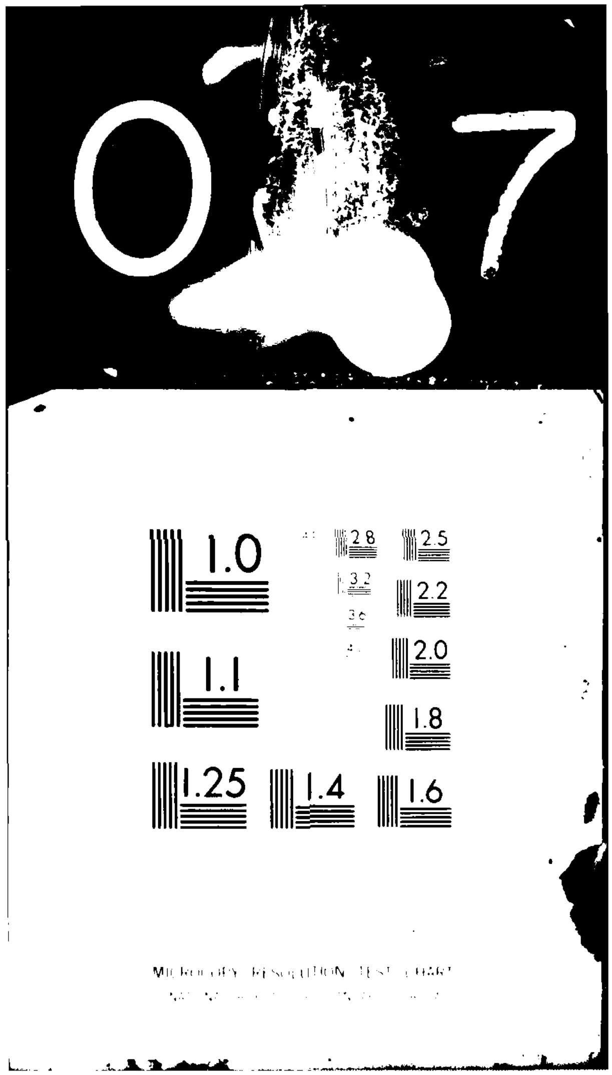
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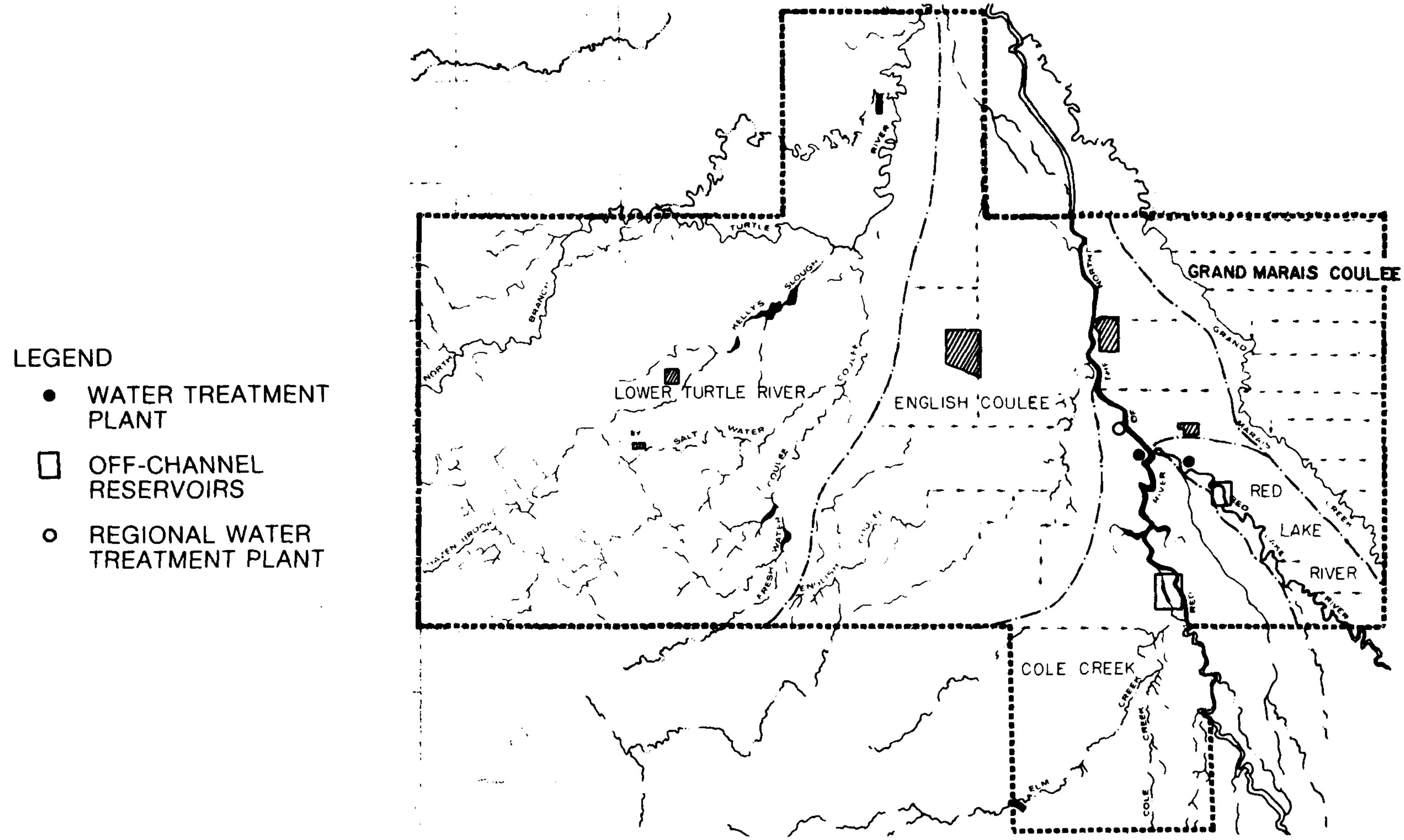

Figure 13 - Off-Channel Storage - Location of Major Facilities

IMPACT ASSESSMENT

GENERAL

This section provides a preliminary impact assessment of the water supply and treatment alternatives. Consideration is given to environmental, social, and economic factors. The impact analysis is very preliminary at this stage and will be developed in more detail as alternatives are more clearly defined and more site-specific evaluations needed to forecast impacts are conducted.

An impact analysis matrix for "no action" and the three water supply alternatives is shown in table 19. An impact analysis matrix for "no action" and separate water treatment versus a joint water treatment facility is shown in table 20. At this stage of the study, differences in impacts between a groundwater treatment plant and a surface water treatment plant are not considered significant enough to evaluate. The major differences in impacts between groundwater and surface water alternatives are in the means of developing and transmitting the water supply.

ENVIRONMENTAL

The "no action" alternative for water supply and treatment will have no significant effect on environmental factors as showr in tables 19 and 20. The use of the Elk Valley aquifer has several significant impacts. About 900 acres will be required for the well field to meet study area 2030 water supply needs and 32 miles c: pipeline will be constructed. This alternative also will result in an increase in the flow of the Red River of the North as the well water is used and passes through the sewage systems of the cities with ultimate discharge to the Red River. During extreme low-flow periods, the flow increase could be significant.

An off-channel storage of river water supply alternatives will require up to 1,400 acres for a storage reservoir to meet water supply needs of the urban area for the year 2030 during 30-day duration, once-in-50-year low flow. Such a reservoir could have beneficial effects as a habitat for certain wildlife species.

Table 19 - Impact analysis matrix, water supply source alternatives

Impact Category	Alternative: No Action	Elk Valley	Rivers with Storage	Garrison Diversion
Environmental				
Land	No effect	Construction activities affect about 900 acres for well field and 32 miles for pipeline	Construction activities affect about 1,400 acres for storage reservoirs	No effect
Man-Made Resources	No effect	Depends on pipeline route	Little effect	No effect
Natural Resources	No effect	Depends on pipeline route	Storage reservoir may have some effect	No effect
Water Quality	No effect	May improve by adding to river flow	Possible adverse effect at low flow	Mav have beneficial effect up-stream of urban area
Air Quality	No effect	No effect	No effect	No effect
Wildlife	No effect	No effect	Provides habitat	No effect
Hydrologic	No effect	Adds flow to river	Modifies river flow	Increases low flow upstream of urban area
Social				
Noise	No effect	During construction	During construction	No effect
Displacement of people	No effect	Depends on well field location	Depends on reservoir site	No effect
Aesthetics	No effect	No significant effect	No significant effect	No effect
Community Cohesion	No effect	No effect	No effect	No effect
Community Growth	Impaired	No constraint	No constraint	No constraint
Historical & Archaeological	No effect	Possible impact at well field	Possible impact at storage reservoir	No effect
Transportation	No effect	May be some disruption during construction	No significant effect	No effect
Economic				
Property Values	May be impaired	No effect	No effect	No effect
Tax Revenues	No change	May increase	May increase	May increase
Public Facilities	No change	Increase	Increase	Increase
Public Services	No change	Increase	Increase	Increase
Employment	May not increase	Increase	Increase	Increase
Business and Industrial Activities	Impaired	Increase	Increase	Increase
Agricultural Land Lost	None	About 900 acres for well field	Up to 1,400 acres for storage reservoirs	None

Table 20 - Impact analysis matrix water treatment alternatives

Impact	Alternative: No Action	Alternative: Separate for Cities	Alternative: Joint for Cities
Environmental			
Land	No effect	No effect if existing sites are used	Possible effect if new location
Man-made Resources	No effect	No effect if existing sites are used	May be effect with new location
Natural Resources	No effect	Probably no effect	Probably no effect
Water Quality	No effect	No effect	No effect
Air Quality	No effect	No effect	No effect
Wildlife	No effect	No effect	No effect
Hydrologic	No effect	Increased water consumption will reduce streamflow	Increased water consumption will reduce streamflow
Social			
Noise	No effect	During construction	During construction
Displacement of People	No effect	No effect with existing sites	May cause displacement if new site is chosen
Aesthetics	No effect	No effect	No effect
Community Cohesion	No effect	No effect	May enhance
Community Growth	Impaired	Enhance	May have effect in growth pattern
Historical & Archaeological	No effect	No effect	No effect
Transportation	No effect	No effect	No effect
Economic			
Property Values	May be impaired	No effect	May enhance
Tax Revenues	No change	May increase	May increase
Public Facilities	No change	Increase	Increase
Employment	May not increase	Increase	Increase
Business & Industrial Activities	Constrained	No constraint	No constraint
Agricultural Land Lost	No effect	Minimal	Minimal

Use of Garrison Diversion water has few significant environmental impacts. Release of diversion water during low-flow periods may have beneficial effects on water quality upstream of the urban area as a result of the net increase in flow.

The differences in environmental effects between separate and regionalized water treatment facilities is primarily in the sites selected for the facilities. A joint water treatment facility for Grand Forks and East Grand Forks may require a new site, which could have negative environmental impacts depending on the specific location.

SOCIAL

Community growth will be impaired if water supply and treatment alternatives are not developed to meet the needs of the study area. If adequate water supplies are provided, there should be no constraint to projected growth. Noise during construction activities will occur. Displacement of people depends on the specific sites selected for well fields, reservoirs, and water treatment facilities. Garrison Diversion water has no significant negative social impacts because construction of new facilities is not required.

A regional water treatment facility may have some effect on the growth pattern of the urban area because one regional authority will be making decisions as to water supply for new developments instead of two separate entities.

ECONOMIC

If no action is taken to develop and expand water supply and treatment facilities for the study area, business and industrial activities will be impaired. Growth will be impaired and employment will not increase. A reliable water supply is essential for industrial growth and expansion. The Elk Valley aquifer and river with storage water supply alternatives both require a considerable amount of land for use as well

fields and reservoir sites. Land used for off-channel storage will be along the Red or Red Lake Rivers and may not currently be productive agricultural land. Selection of specific sites in later studies will allow a specific evaluation of this factor. The water treatment alternatives will not require significant amounts of agricultural land for expansion or construction of facilities at a new site.

EVALUATION

GENERAL

This section evaluates the various water supply and treatment alternatives that have been screened on the basis of cost in the section beginning on page 62 and given a preliminary impact analysis in the previous section. The supply alternatives that will be evaluated are the use of groundwater from the Elk Valley aquifer or use of surface water from the Red River of the North supplemented by off-channel and/or in-channel storage. The treatment alternatives are joint or separate treatment for Grand Forks and East Grand Forks with either surface water treatment, advanced surface water treatment, or softening of groundwater depending on the water supply source and requirements for treated water quality.

ECONOMICS

Table 21 summarizes total study area costs according to categories of ways of supplying water along with cost rankings. Use of the Dakota aquifer and reuse of wastewater lagoon effluent were previously eliminated because of excessive costs. Costs shown in table 21 indicate that if surface waters remain the primary water supply source, off-channel storage with joint treatment for all users except the rural areas is the least costly alternative if only conventional surface water treatment is required. A combination of off-channel/in-channel storage with joint treatment for Grand Forks and East Grand Forks is the second ranked alternative for conventional surface treatment.

If carbon adsorption is required for surface water treatment as stated in proposed Environmental Protection Agency requirements (designated as advanced treatment), alternatives that use the Elk Valley aquifer supply for Grand Forks become more comparable in costs to advanced surface water treatment alternatives. The least costly advanced surface water treatment alternative is ranked number 8 and is separate treatment with the use of a combination of off-channel/in-channel storage. The two alternatives using separate treatment under the Elk Valley supply use groundwater for Grand Forks and surface water for East Grand Forks. Using the Elk Valley aquifer supply for both cities as shown in the joint treatment alternative is the most costly alternative.

Table 21 - Alternative cost summary and rankings

Option	Alternatives[1]	Total Equivalent Annual Cost	Cost Ranking
Garrison			
Surface	GF(A),EGF(C1),I(A),R(A)	4,126,000	7
Advanced	GF(B),EGF(C2),I(A),R(A)	4,858,000	14
Surface	JOINT(B),I(A),R(A)	4,119,000	6
Advanced	JOINT(E),I(A),R(A)	4,878,000	15a
Off-Channel			
Surface	GF(C(,EGF(D1),I(A),R(A)	3,903,000	5
Advanced	GF(D),EGF(D2),I(A),R(A)	4,628,000	11
Surface	JOINT(C),I(A),R(A)	3,770,000	3
Advanced	JOINT(D),I(A),R(A)	4,710,000	12
Surface	JOINT(F),R(A)	3,603,000	1
Advanced	JOINT(G),R(A)	4,550,000	10
Elk Valley			
Surface	GF(E),EGF(A),I(A),R(A)	4,795,000	13
Advanced	GF(E),EGF(B),I(A),R(A)	4,878,000	15b
Surface	JOINT(A),I(A),R(A)	5,300,000	16
Off-Channel/In-Channel			
Surface	GF(H1),EGF(D1),I(A),R(A)	3,847,000	4
Advanced	GF(H2),EGF(D2),I(A),R(A)	4,460,000	8
Surface	JOINT(H),I(A),R(A)	3,628,000	2
Advanced	JOINT(I),I(A),R(A)	4,496,000	9

[1]Notations refer to Grand Forks (GF), East Grand Forks (EGF), Industries (I), and Rural Users (R). The alternatives used in each combination refer to the alternatives presented in the section beginning on page 62.

The alternatives that use Garrison Diversion water are generally more expensive than the surface water storage options. The costs of these alternatives depend on the cost of the diversion water which was taken as \$50/acre-foot in this study. This cost figure needs to be further evaluated in stage 3.

The alternatives evaluated can be combined in a variety of different ways, but the alternatives shown in tables 18 and 21 give a good indication of the relative cost effectiveness of various combinations. On the basis of this cost analysis, it appears that joint treatment is worth further analysis and that use of the Elk Valley aquifer as a source of water supply is a possible alternative if advanced water treatment is required.

Indirect economic impacts of the various alternatives are in the use of natural resources. Surface water treatment uses a number of chemicals such as alum, lime, soda ash, activated carbon, and chlorine. A water softening plant for a groundwater supply would use lime, soda ash, alum, and chlorine.

Energy used in the operation of water treatment and transmission facilities is also an important consideration from the standpoint of future escalating energy costs and because nonrenewable resources are often used to produce energy. The use of groundwater wells in the Elk Valley aquifer would require considerable quantities of energy to pump this water to Grand Forks.

ENVIRONMENTAL QUALITY

Environmental impacts of the alternatives are summarized in table 19 and discussed in the preceding section. A major difference in potential effects on environmental quality exists in use of the Elk Valley aquifer versus continued use of the Red Lake and Red Rivers. Use of the Elk Valley aquifer results in a net increase in flow in the Red River when the groundwater is discharged after passage through the sewerage system. This increase is significant during extremely low-flow periods. Extreme low flows in the Red River of the North have been estimated at 10 cfs now and with increased upstream consumption as low as 6 cfs by 2020. If Grand Forks converted to a groundwater supply in 1980, the estimated average daily water demand of 7.37 mgd (11.4 cfs) would not be withdrawn from the Red River. Instead, about 80 percent or about 9 cfs of the water used would be discharged to the river after wastewater treatment. This results in almost 100 perc t net flow increase in the Red River which could have a significant pos. ive effect on aquatic life and water quality.

Other significant environmental impacts occur during construction activities. The Elk Valley aquifer supply uses up to 900 acres for a well field with 32 miles of water transmission line. Off-channel storage options use up to 1,400 acres for storage reservoirs. Specific effects on environmental quality depend on sites and routes selected and should be evaluated in more detail in stage 3.

Joint water treatment alternatives will require concentration of water treatment facilities at one site and may result in different effects on environmental quality during construction activities than continued expansion at separate sites. Again, a site specific evaluation in stage 3 studies will determine if this is a significant factor.

SOCIAL WELL-BEING

For the economic and social well-being of the residents of the study area, it is essential to have sufficient quantities of potable water. All of the alternatives developed meet projected water demands. The implementation of any one of these alternatives will enhance the prospects for future business and industrial growth in the study area.

Adoption of any of the alternatives will require land acquisition for well fields and reservoirs. The total land involved is similar for either groundwater or surface water supply systems. The land used for off-channel reservoirs would not be useful for other functions unless they are developed as multipurpose reservoirs. Because of well spacing, land in well fields could be farmed.

REGIONAL DEVELOPMENT

Adequate water supplies are essential for continued regional development. If no action is taken to expand water supply and treatment systems, growth in the study area will be definitely hindered. Joint or regional water treatment systems may have a different effect on regional development than separate systems because one regional authority instead of two entities will be making decisions as to water supply for new developments. This may change the growth pattern of the urban area.

Use of the Elk Valley aquifer may make water supply more accessible and of lower cost to developments along the transmission line and nearer the well field west of Grand Forks. Water treatment facilities could be

located at the well field instead of in the urban area. Treated water could then be pumped through transmission lines to Grand Forks. This water would then be immediately available to developments along the transmission line.

INSTITUTIONAL

The major institutional consideration for the developed alternatives is in the area of joint versus separate treatment facilities. Institutional differences between groundwater and surface water supplies are minor, but water rights would have to be obtained for use of the Elk Valley aquifer and rights-of-way obtained for the 32 miles of transmission lines.

Regionalization can involve joint use of physical facilities or joint management of existing facilities. A single water utility for the urban area has some managerial and logistic advantages. One water utility may need fewer total people to manage and operate water supply services. Fewer total people would have to be trained to do laboratory work and specialized equipment maintenance. Fewer people may be needed to handle billings, and one management staff would be able to supervise the operation of the utility.

A single water utility would probably make it easier to logically plan and control housing development on prime farmland outside the 2-mile fringe adjacent to the urban area. When it is time to expand treatment facilities, one addition or one new facility would be constructed to meet water supply needs of the study area. If the water utilities in Grand Forks and East Grand Forks continue to operate separately, each may have to make major capital additions in 10 to 15 years.

If Grand Forks and East Grand Forks do join together and form one water utility, some form of an agreement must be made for the administration of such a utility. A single governing board may have to be formed to oversee the utility's operation. A report by Kannowski (48) concerning an institutional analysis of the study area concludes that "cooperation in water resources management can be arranged more satisfactorily by formal agreement than by contract or by formation of a district." If the utility is to adequately serve the major industrial

water users in the urban area, it will have to respond to their needs. Perhaps the governing committee could have members or possibly special advisors from the industrial user group. Perhaps rural water users, if applicable, could be represented in a similar manner to have a voice in urban fringe development. Fair representation is an issue that would have to be worked out to induce rural and industrial users to accept the concept of a single water utility for the study area. A suggested proposed bi-state agreement is set forth in the institutional report by Kannowski (48).

Maintaining separate water utilities for Grand Forks and East Grand Forks offers the advantage of not changing the existing administration and management of water supply services. The local entities which have financed, constructed, and operated water supply and treatment facilities would continue to own, operate, and expand those facilities. No institutional or legal changes are required and local control, local autonomy, and political accountibility are preserved.

RECREATION

Construction of off-channel storage reservoirs offers potential for a multiple-use project involving boating, fishing, and other water-based recreation. The open water bodies also would provide wildlife habitat which may lead to land-based recreation. The potential for park land development is available for either the well field or near reservoirs.

RELIABILITY

The reliability of surface water alternatives is a function of the probability of low river flows. The probability of low flows is based on historical flow records; however, low flows in future years are difficult to predict, particularly when upstream river consumption patterns change with time. Off-channel storage alternatives were based on meeting water demands to the year 2030 for the 30-day duration, 50-year low-flow event which was based on historical flow records. One problem with accurately assessing the reliability of this system is that, by the year 2000, flow records may show that the probability of this event has changed considerably.

The surface water alternatives provide reliability for all but the rarest events. Therefore, there is always the possibility that for a prolonged drought of greater than about 50-year frequency water supplies would be inadequate. Some sort of drought action plan would need to be developed and implemented for such an occurrence.

The Elk Valley aquifer supply is totally reliable if recharge is adequate to meet withdrawals as appears to be the case. The potential yield of this aquifer should be evaluated in more detail in stage 3. The reliability of the Elk Valley aquifer supply also depends on maintaining the relatively long (32 miles) transmission lines. Parallel lines have been included in the alternatives to enhance reliability.

CONCLUSIONS AND RECOMMENDATIONS

A wide variety of water supply and treatment alternatives have been examined for the study area. It would not be cost effective for rural water users to connect to a regional water treatment and supply system. Use of the Dakota aquifer (requiring desalination) and wastewater lagoon effluent reuse was not cost effective compared to continued use of river water supplies with off-channel and/or in-channel storage.

To ensure adequate reliability during low flows, off-channel and/or in-channel storage is required for surface (river) water supplies. The most cost-effective alternative, if conventional surface water treatment is required, is the the continued use of river water supplemented by storage.

If advanced surface water treatment (granular carbon filtration) is required, as proposed by the Environmental Protection Agency, alternatives that use the Elk Valley aquifer as a water supply source become economically competitive with surface water supply alternatives.

Use of Garrison Diversion water to supplement river water supplies depends on the cost paid for this water. Procedures and mechanisms for obtaining this water, if the Garrison Diversion project is implemented, need to be evaluated in more detail.

Joint water supply and treatment systems for Grand Forks and East Grand Forks appear to be cost effective compared to separate systems.

An impact assessment and evaluation of the alternatives indicated that no major factors would eliminate the more cost-effective alternatives as summarized above. The costs used in this analysis are general in nature; costs, design details, and impacts of these alternatives should be refined in stage 3 of the urban study. It is therefore recommended that state 3 investigations develop and assess the following in more detail:

1. Supplying the urban area with surface water supplemented by off-channel and/or in-channel storage facilities or Garrison Diversion water. Water treatment facilities should be evaluated for both conventional surface and advanced surface water treatment.

2. Supplying the urban area with groundwater from the Elk Valley aquifer. Aquifer yields should be evaluated along with well fields, transmission, and treatment facilities.

3. Evaluation of joint treatment facilities for Grand Forks and East Grand Forks versus separate treatment facilities. The evaluation should consider not only physical facilities but also the economic and managerial implications of a single water utility versus separate systems for the urban area.

ATTACHMENT A

REFERENCES

ATTACHMENT A

REFERENCES

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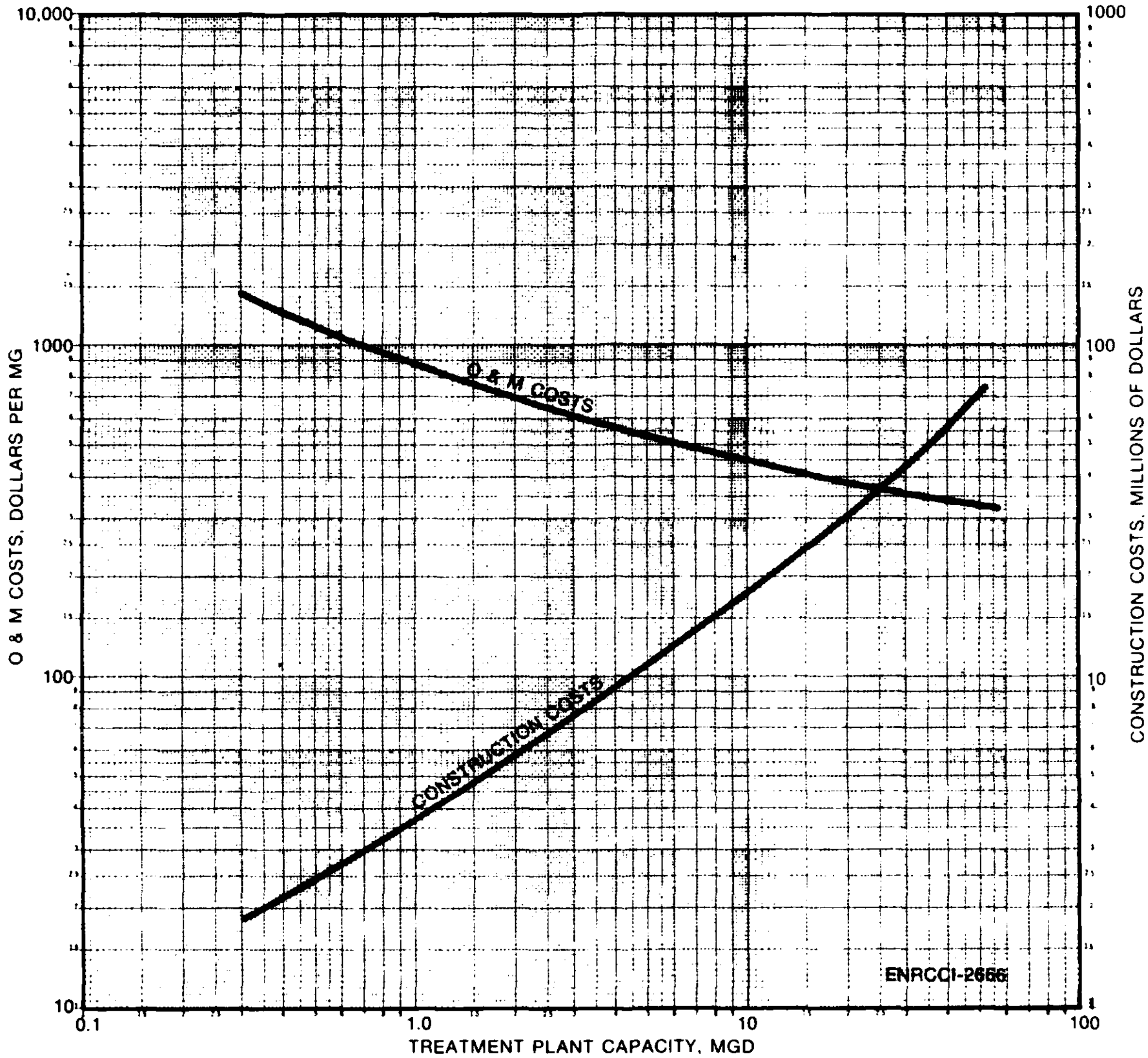
ATTACHMENT B

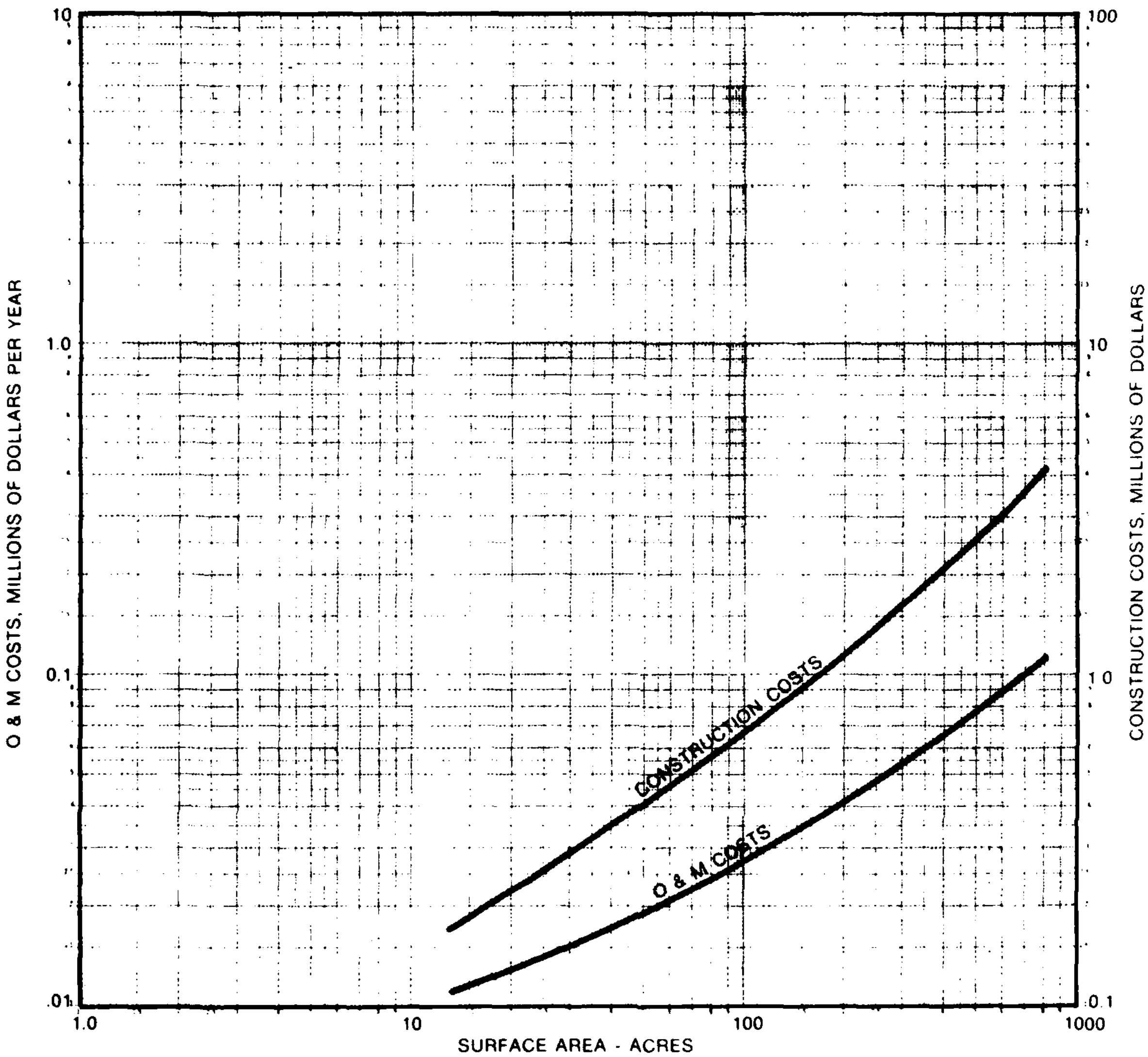
COST INFORMATION



Desalination Treatment

COSTS BASED ON:
1. UPDATED CONSTRUCTION COSTS AND O & M COSTS FOR REVERSE OSMOSIS DESALINATION (51).
2. *CONSTRUCTION COSTS AND O & M COSTS FOR CHLORINATION - SCI.*
3. COSTS WERE UPDATED USING THE ENGINEERING NEWS RECORD CONSTRUCTION COST INDEX.

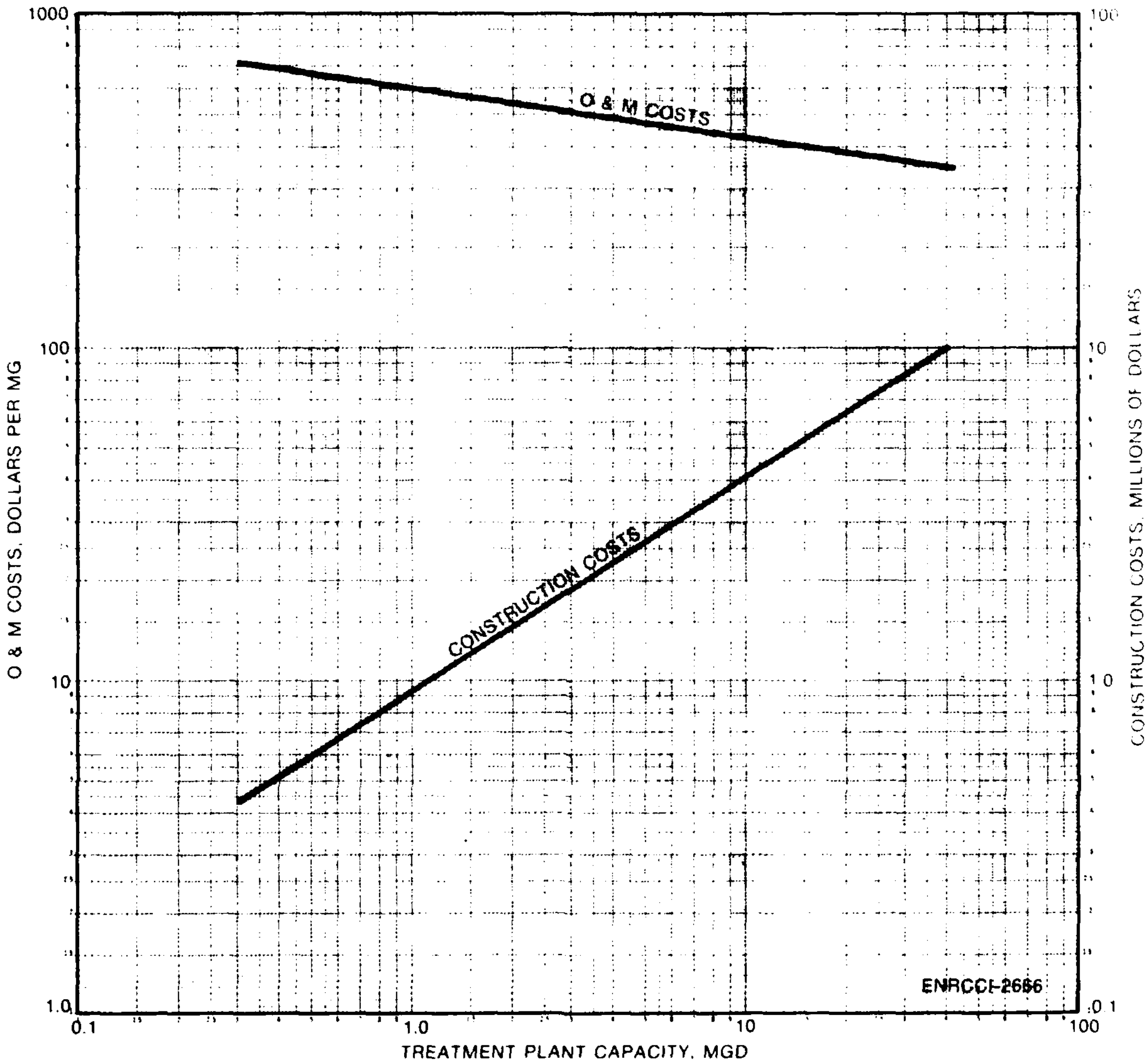
Figure B-1



Reservoir Costs

COSTS BASED ON: 10' WATER DEPTH, 4:1 SIDESLOPES, 3' FREEBOARD.
COSTS INCLUDE: EXCAVATION, BANK PROTECTION, FENCING.

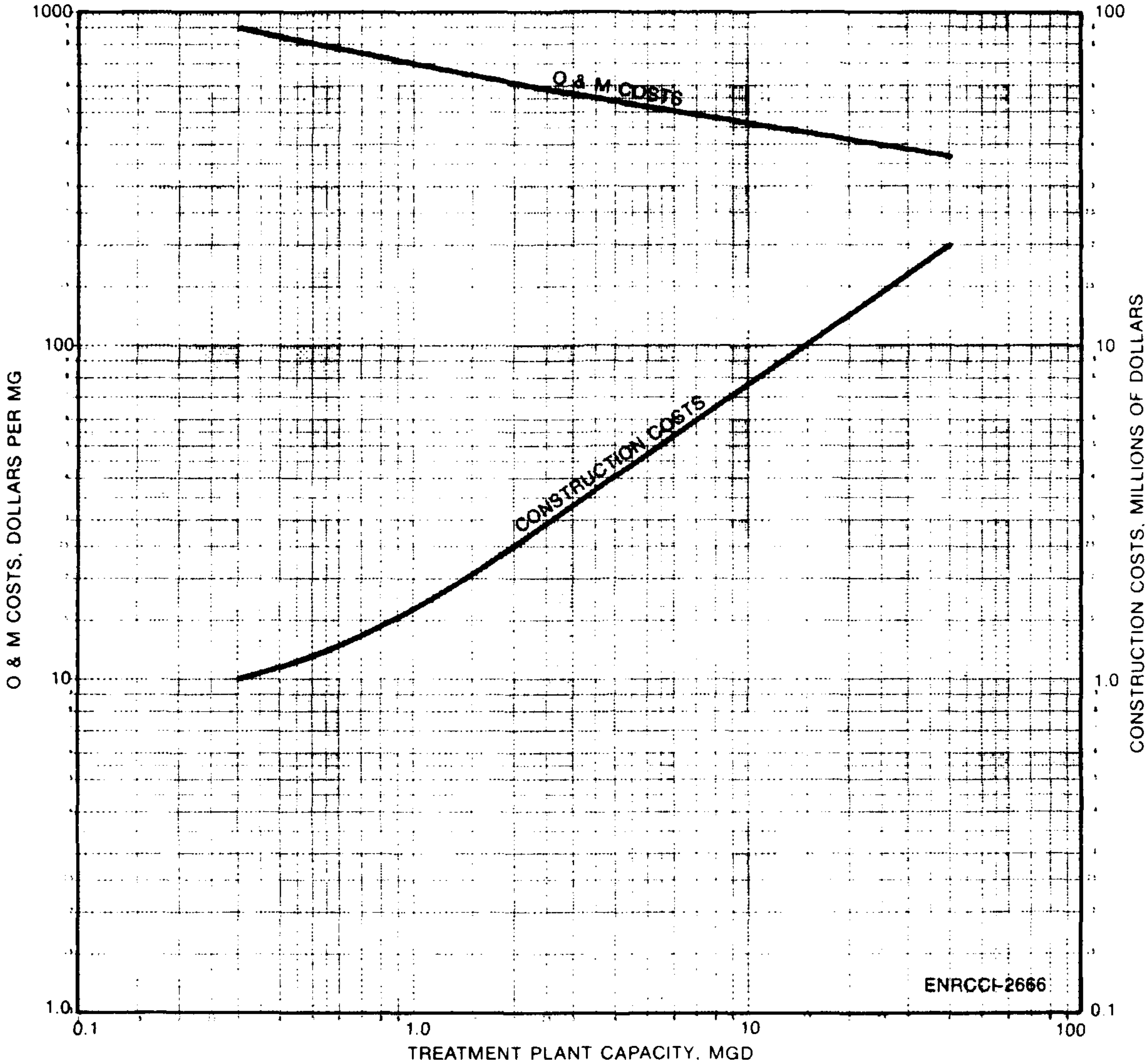
Figure B-2



Surface Water Treatment

COSTS BASED ON:
1. UPDATED CONSTRUCTION COSTS FROM FIGURE 6-2 (52)
2. UPDATED O & M COSTS FOR GRAND FORKS (50) AND EAST GRAND FORKS (29).
3. COSTS WERE UPDATED USING THE ENGINEERING NEWS RECORD CONSTRUCTION COST INDEX.

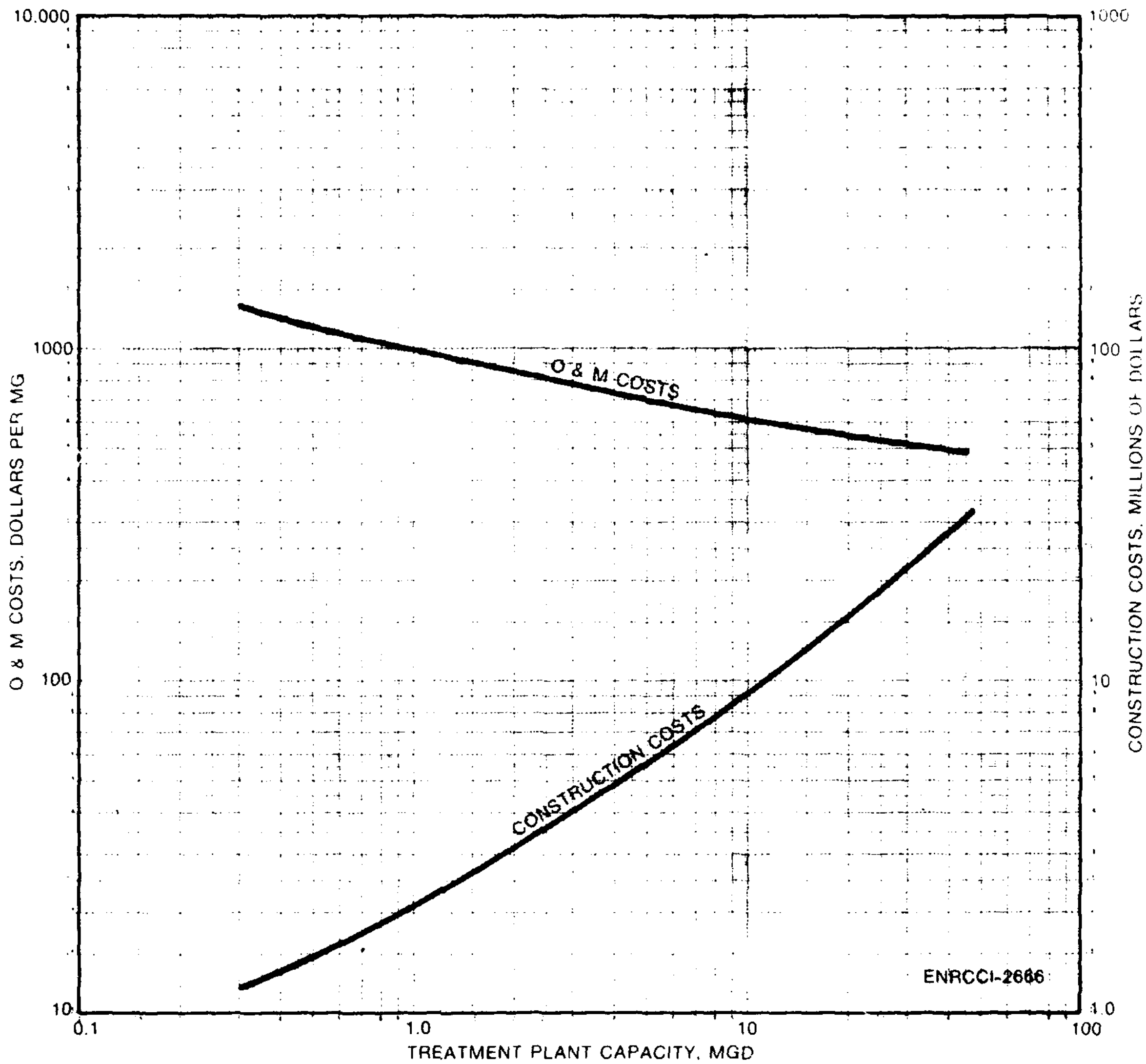
Figure B-3



Advanced Surface Water Treatment

COSTS BASED ON:
1. UPDATED CONSTRUCTION COSTS FROM FIGURE 6.2 (52)
2. UPDATED O & M COSTS FOR GRAND FORKS (50) AND EAST GRAND FORKS (29).
3. COSTS WERE UPDATED USING THE ENGINEERING NEWS RECORD CONSTRUCTION COST INDEX.
4. CARBON CONTACT 20 MIN., DOSAGE 300 LBS/MG.
5. COSTS INCLUDE CARBON REGENERATION
6. OZONE DOSE 5 MG/L.

Figure B-4



Water Reuse Treatment

COSTS BASED ON:

1. CONSTRUCTION AND O & M COSTS FOR WASTEWATER PUMPING, CARBON ADSORPTION, SELECTIVE ION EXCHANGE, BALLAST POND, AND CONTROL BUILDING - SCI.
2. UPDATED CONSTRUCTION COSTS FOP SOFTENING, FILTRATION, AND CHLORINATION.
3. O & M COSTS FOR THE SOFTENING, FILTRATION, AND CHLORINATION PART OF THE REUSE PLANT ARE BASED ON UPDATED O & M COSTS FOR GRAND FORKS (50) AND EAST GRAND FORKS (29).
4. COSTS WERE UPDATED USING THE ENGINEERING NEWS RECORD CONSTRUCTION COST INDEX.

Figure B-5

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A REFERENCES

B LIST OF ABBREVIATIONS

STAGE 3 WATER SUPPLY STUDY

FINAL REPORT

INTRODUCTION

GENERAL

The stage 3 report develops plans for providing adequate quantity and quality water to the urban area. It summarizes the problem identification; alternative formulation, impact assessment, and evaluation; and institutional and implementation analyses. In addition, a drought action plan for Grand Forks and East Grand Forks is presented.

This report builds on the findings of and local, State, and Federal comments on the Stage 2 Water Supply Study. The stage 2 study screened a wide range of potential alternatives and identified the most promising alternatives which merited further study. Stage 3 analyzes the decreased number of most promising alternatives in an increased level of detail.

The stage 2 analysis eliminated many alternatives or combinations of alternatives because they were not cost effective. These alternatives involve various combinations including joint and/or separate use of the following:

1. Dakota groundwater aquifer (requiring desalination), as a source of supply.
2. Wastewater lagoon effluent reuse as a source of supply.
3. Rural water users connecting to a regional water treatment and supply system.
4. Self-supplied industries connecting to a regional water treatment and supply system.

Descriptions of the alternatives considered in stage 2 and details of the analyses and conclusions were presented in the Stage 2 Water Supply Study.

SCOPE

This report focuses on the stage 3 investigation, which was to accomplish the following:

1. Very briefly review and revise information developed in stage 2 including water supply and treatment problems, water demands, design criteria, legal requirements, projections, and public concerns.

2. Reevaluate the base conditions including socioeconomic, environmental, and water management for the "without project" situation.

3. Evaluate and develop preliminary plans and designs for using the following water supply sources:
   a. Red River of the North and Red Lake River including in-channel and/or off-channel storage reservoirs.
   b. Elk Valley aquifer.
   c. Garrison Diversion.
   d. Conservation measures.

4. Develop complete alternative plans for adequately supplying water demands. These alternative plans include the preliminary designs and programs for source of supply, water transmission facilities, water treatment facilities, and institutional arrangements. These plans include separate and joint systems for Grand Forks and East Grand Forks.

5. Develop comparable cost analyses to assess the costs of each overall alternative for the 50-year study period.

6. Generally determine, identify, describe, and measure the impacts that will result from each alternative.

7. Evaluate each alternative plan to determine if it achieves the overall objectives, compare beneficial and adverse impacts, determine the alternatives' contribution and fulfillment of the System of Accounts and the Principles and Standards.

8. Select the most feasible and cost-effective alternative.
9. Identify and analyze existing institutions which implement and control water systems. If necessary, investigate the need for modifying existing institutions or developing new ones.
10. Develop an implementation plan for carrying out the selected plan. Agencies responsible for financing, constructing, operating, and maintaining the selected alternative are to be identified.
11. Develop a drought action plan consisting of nonstructural measures to be undertaken during a severe drought.

STUDY AREA

Figure 1 shows the study area established for the Grand Forks-East Grand Forks Urban Water Resources Study.[1] The area includes the major population centers of the city of Grand Forks, North Dakota, the city of East Grand Forks, Minnesota, and the Grand Forks Air Force Base near Emerado, North Dakota. The study area is located within Grand Forks County, North Dakota, and Polk County, Minnesota, and includes the following townships:

1. Grand Forks County townships of Ferry, Mekinock, Blooming, Rye, Falconer, Chester, Oakville, Brenna, Grand Forks, and Walle.
2. Polk County townships of Grand Forks, Sullivan, Rhinehart, and Huntsville.

A comprehensive overview of the study area is provided in the Background Information Appendix.

Figure 2 shows the study area which is within the Red River of the North basin. The Red River of the North and the Red Lake River are major rivers which directly affect the study area.

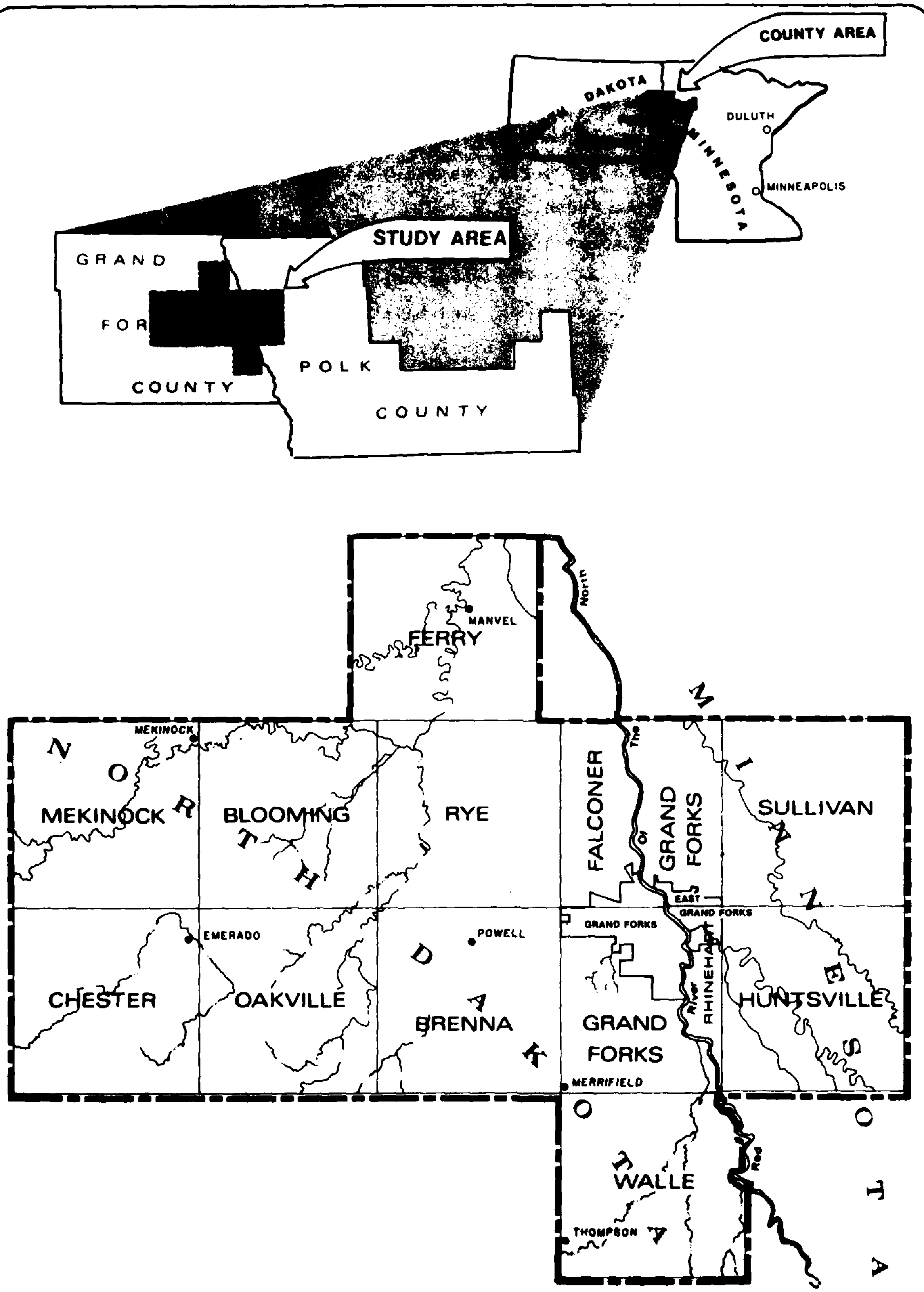


Figure 1 - Study Area

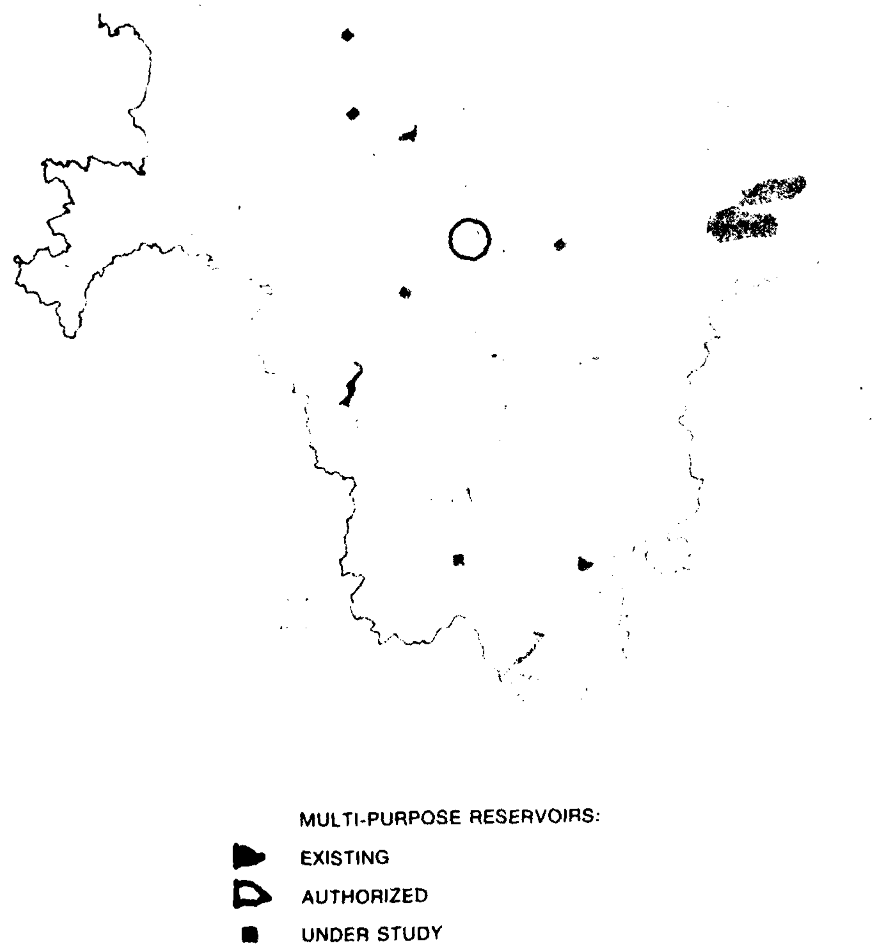


Figure 2 - Red River of the North Basin

CLIMATE

The Grand Forks-East Grand Forks area has a continental climate characterized by wide variations in temperature, light to moderate precipitation, plentiful sunshine, and nearly continuous air movement.[2] The National Weather Service classifies the area as cold temperature, no distinct dry season, and cold summer.

Table 1 summarizes temperature, precipitation, and mean degree days for the University of North Dakota weather station. This station is located in Grand Forks and has continuous records from January 1898.

The mean annual evaporation is about 28 inches or about 8 inches greater than the mean annual precipitation of 20.02 inches.[3] For the Corps of Engineers' reservoirs of Orwell Lake, Red Lakes, Lake Ashtabula, and Homme Lake, the 1936 average net evaporation (evaporation minus precipitation) was 28.2 inches.[4] The year 1936 had the highest average net evaporation for these reservoirs for the period 1929 to 1976.

Table 1 - Climatological data for Grand Forks

Month	Mean Temperature[1]	Mean Degree Days[2]	Mean Precipitation[1]
January	4.2	1,876	0.53
February	8.4	1,576	0.54
March	23.3	1,314	0.80
April	41.5	717	1.56
May	54.3	341	2.47
June	63.8	105	3.47
July	69.2	31	2.99
August	67.0	43	2.81
September	56.7	252	2.08
October	44.9	608	1.29
November	28.8	1,167	0.86
December	11.1	1,646	0.62
Annual	39.3	9,676	20.02

[1]Period of record 1898 to 1966 (69 years).

[2]Period of record 30 years. Base is 65°F. Mean degree day is a departure of one degree for one day below the mean daily temperature and is used for determining heating requirements.

Source: Reference 2

WATER SUPPLY DEMANDS

GENERAL

Water supply demands are the basis for determining the adequacy of existing and potential water supply sources and water treatment facilities. The water supply demands which were developed in the stage 2 study have been revised and serve as input for this study. These revisions are based on additional data collected and local reviews. Rural water demands are not addressed in this study because they are not included in any of the alternatives being considered.

CURRENT URBAN WATER DEMANDS

Table 2 summarizes the Grand Forks and East Grand Forks historical annual water consumption, which is water delivered to the water distribution systems. Water consumption has steadily increased, indicating increased growth and increased water use by existing users.

Table 3 lists the monthly breakdown of water demands for 1976 which is used as a base year. The current urban water demands are summarized from a variety of sources and previous studies.

Table 4 presents updated water demands for the major industrial water users served by Grand Forks. The information presented in tables 3 and 4 represents surface water demands or water pumped from the rivers. A limited amount of groundwater is used in the urban area for residential and industrial water supply. The Pillsbury Company is the only major industrial user of groundwater in the urban area.

Table 2 - Historic urban water consumption

	Annual Average Consumption in mgd						
	1970	1971	1972	1973	1974	1975	1976
East Grand Forks							
Average Industrial Use	0.366	0.359	--	--	0.452	--	0.440
Average Residential & Commercial Use	0.387	0.381	--	--	0.414	--	0.725
Total Average Daily Use[1]	0.753	0.740	0.890	0.877	0.866	0.883	1.165
Grand Forks							
Average Supply to Air Force Base	1.07	1.06	1.21	1.24	0.96	0.81	1.13
Average Industrial Use	0.82	1.12	1.30	1.33	1.36	0.94	1.16
Average Residential & Commercial Use	2.98	3.66	3.75	3.59	4.00	4.31	4.26
Total Average Daily Use[1]	4.87	5.84	6.26	6.16	6.32	6.06	6.55

[1] Average daily use is the amount of water in each city delivered to the distribution system. From 10 to 15 percent more raw water intake has been required in the past due to losses in water treatment. The recent addition (August 1977) of the water treatment sludge and filter backwash water treatment facility should reduce this for Grand Forks. The water use reported here is higher than water billed in each city due to unaccounted for losses in the distribution system. These are estimated at 5 to 10 percent based on Grand Forks data.

Source: Stanley Consultants

Table 3 - 1976 Urban water demand

Water Withdrawals		Water Use in Month (Million Gallons)												Annual Average
User	Source	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	(mgd)
East Grand Forks	Red Lake River	35.25	33.75	35.52	28.50	36.61	36.56	44.24	41.12	37.49	35.54	33.61	34.09	1.18
Grand Forks	Red River	186.64	168.04	179.94	183.78	238.95	218.94	248.68	245.12	210.92	217.71	204.33	198.52	6.86
American Crystal	Red Lake River	17.89	7.99	2.13	0	0	0	0	51.91	20.04	51.67	10.29	0.32	0.44
Burlington Northern[1]	Red Lake	9.55	8.68	8.68	8.68	6.94	3.47	--	0.88	1.74	2.60	6.94	6.94	0.18
Major Industrial Users of City Water														
Grand Forks AFB	(GF)	26.53	25.47	31.60	27.03	37.43	45.22	47.40	45.17	37.68	27.00	26.48	34.93	1.13
International Co-op[2]		1.13	0.59	0.59	0.62	0.56	0.81	0.85	0.52	0.54	14.95	26.93	25.65	0.58
University of N. Dak.	(GF)	5.16	5.58	5.74	5.55	6.00	4.84	4.19	4.27	7.19	5.53	8.86	7.24	0.19
Pillsbury Co.	(GF)	3.51	4.46	5.77	4.64	3.31	0.40	0.09	0.13	3.27	5.90	5.71	6.30	0.12
Bridgeman Creamery	(GF)	0.38	0.54	0.74	1.10	1.39	1.90	1.71	1.85	1.01	0.63	0.62	0.32	0.03
Rogers Brothers[3]		0.63	1.83	1.88	1.69	1.60	0.87	--	--	--	0.47	2.05	2.41	0.04
N. Dak. State Mill	(GF)	1.29	1.22	1.23	1.37	1.23	1.30	1.17	1.40	1.51	1.05	1.24	1.43	0.04
Great Northern RR	(GF)	1.60	1.59	1.75	1.87	2.00	1.35	0.98	0.92	1.05	1.60	2.07	1.64	0.05
United Hospital	(GF)	0.22	0.26	0.30	0.32	1.04	3.36	3.63	3.37	3.38	2.34	2.10	2.20	0.06
American Crystal	(EGF)	5.15	6.30	5.08	1.75	0.48	0.45	5.83	6.74	9.50	17.73	17.48	21.57	0.27
Ryan Potato[4]	(EGF)	0.77	0.63	0.49	0.79	0.91	0.49	0.11	--	--	0.30	0.72	0.77	0.02
Burlington Northern[5]	(EGF)	9.04	8.54	9.29	9.79	6.02	2.20	0.47	1.37	1.08	3.36	3.64	3.62	0.16

[1] Limited information is available for the Burlington Northern Industrial area in East Grand Forks. The values reported here are maximum monthly use in 1970-71 when King of Spuds and Old Dutch were big water users. With King of Potatoes and Northern Potato now operating, the water use may be less than values indicated.

[2] Water use averaged 28.2 MG/month in January 1977 to May 1977, which is more representative of future use than values reported as actual use in 1976 above.

[3] Reported no longer in operation July 1977.

[4] 1974 data.

[5] 1974 data for city water supply to King of Spuds and this industrial area.

Source: Stanley Consultants

Table 4 - Major industrial water demands in Grand Forks, 1977-1978

Major Industrial User of City Water	Water Use in Month (Million Gallons) 1977 Nov.	1977 Dec.	1978 Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Annual Average (mgd)
Grand Forks AFB	19.67	31.47	24.78	29.44	32.35	29.98	28.08	36.52	43.44	47.08	27.46	26.72	1.03
International Co-op	25.57	21.33	22.90	26.36	26.67	26.01	21.93	9.84	2.10	1.77	7.42	21.96	0.59
University of North Dakota	19.88	13.64	15.33	16.65	21.55	15.29	12.67	10.98	10.03	11.11	13.46	13.08	0.48
Pillsbury Co.	6.20	5.56	7.14	6.30	8.14	9.56	8.83	2.36	0.27	0.47	5.46	8.90	0.19
Bridgeman Creamery	0.42	0.32	0.25	0.41	0.38	0.63	0.83	1.30	1.38	1.33	0.68	0.47	0.02
North Dakota State Mill	0.90	0.79	1.09	1.02	0.96	0.88	0.66	0.59	0.69	1.02	1.05	1.14	0.03
Great Northern Railroad	2.05	1.53	1.47	1.73	1.94	2.09	1.85	1.27	1.09	1.19	1.02	1.35	0.05
United Hospital	1.98	1.59	1.77	1.47	1.71	1.89	2.81	3.03	3.75	3.45	2.98	2.71	0.08
	76.67	76.23	74.73	83.38	93.70	86.33	77.66	65.89	62.75	67.45	59.53	76.33	2.47

Source: Reference 5

As indicated in tables 3 and 4, the largest industrial water users in Grand Forks and East Grand Forks process agricultural products. These industries begin processing when the fall harvest of sugar beets, potatoes, and sunflowers begins. The high water use period for these industries begins in September and October and extends through about May. These industries have a very low water demand in June, July, and August. This water demand pattern is essentially opposite that for the residential and commercial users in the urban area. The overall area water demand pattern reduces the maximum day to average day demand ratio, and, therefore, more efficiently uses the water treatment and distribution facilities.

Variations in water demands are important criteria for designing water supply and treatment facilities. The current ratios of maximum to average are as follows:[5,6]

	Grand Forks	East Grand Forks
Ratio maximum month to average month	1.19	1.24
Ratio maximum day to average day	1.72	1.86

Figure 3 shows the monthly and seasonal variations in water use in Grand Forks and East Grand Forks.

PROJECTED URBAN WATER DEMANDS

The projected urban water demands are based on analysis of the current water demands, other water use records, and review by existing water users. The projections also rely on work completed by others, such as population projections, land use projections, and various assumptions.

Table 5 presents the projected major industrial water demands for the self-supplied industries, industries served by Grand Forks, and industries served by East Grand Forks. The projections are based on the following assumptions:

1. Most of the industries' average water demands are projected to continue at the current level.

Table 5 - Projected major industrial water demands

	Annual Average (mgd)					
	1980	1990	2000	2010	2020	2030
Self-Supplied Industries						
American Crystal[1]	0.45	0.45	0.45	0.45	0.45	0.45
Burlington Industries[1]	0.18	0.18	0.18	0.18	0.18	0.18
Pillsbury Co.[2]	0.15	0.15	0.15	0.15	0.15	0.15
City Supplied Industries						
Grand Forks						
Grand Forks Air Force Base	1.13	1.13	1.13	1.13	1.13	1.13
International Co-op	0.59	0.59	0.59	0.59	0.59	0.59
Pillsbury Co.	0.12	0.12	0.12	0.12	0.12	0.12
University of North Dakota	0.48	0.48	0.48	0.48	0.48	0.48
Bridgeman Creamery	0.03	0.03	0.03	0.03	0.03	0.03
North Dakota State Mill	0.04	0.04	0.04	0.04	0.04	0.04
Great Northern Railroad	0.05	0.05	0.05	0.05	0.05	0.05
United Hospital	0.06	0.06	0.06	0.06	0.06	0.06
New Potato Industry	0.60	0.60	0.60	0.60	0.60	0.60
Other Industries	0.07	0.14	0.33	0.50	0.67	0.83
TOTAL	3.17	3.24	3.43	3.60	3.77	3.93
East Grand Forks						
American Crystal Sugar	0.27	0.27	0.2[illegible]	0.27	0.27	0.27
Ryan Potato	0.02	0.02	0.02	0.02	0.02	0.02
Burlington Industries	0.15	0.15	0.15	0.15	0.15	0.15
Other Industries	0.13	0.20	0.27	0.33	0.40	0.47
TOTAL	0.57	0.64	0.71	0.77	0.84	0.91

[1]Located in East Grand Forks and uses Red Lake River as its source of water supply.

[2]Located in Grand Forks and uses groundwater as its source of water supply.

Source: Stanley Consultants

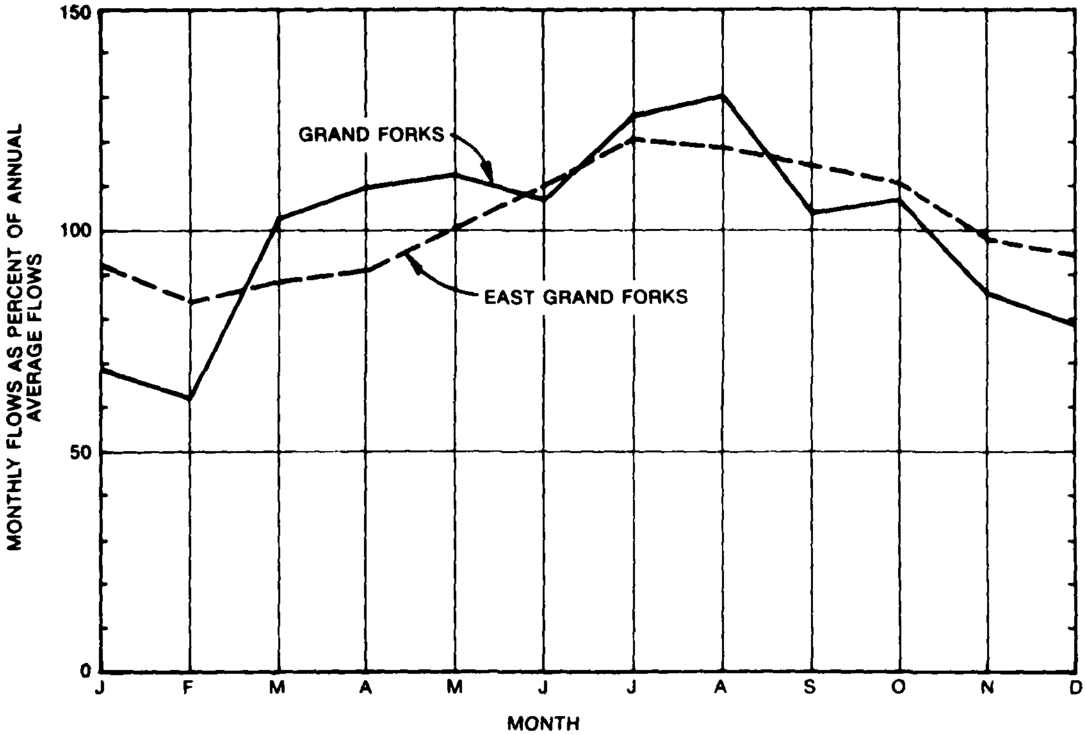


Figure 3 - Seasonal Water Use Trends for Grand Forks and East Grand Forks

2. The Grand Forks Air Force Base will remain in the area, and the estimated water demand through year 2030 will be 1.13 mgd.
3. Based on the industry's projections, American Crystal Sugar is expected to increase its plant capacity without increasing its water demands. This will be accomplished through use of more efficient equipment and recycling of process water.

4. Water demands for the other industries category will increase by 2020 as follows: sugar beet production 195-percent increase, potato production 125-percent increase plus more local processing, and poultry production 160-percent increase.[7]

For residential and commercial users, the projected water demands are based on 100 gpcd (gallons per capita per day). The 100-gpcd value is near the current water use rates in both cities and includes residential and commercial metered consumption plus unaccounted for water losses in the distribution system and wasted backwash water. These projections are also based upon the following population projections:[8]

	1975	1980	1990	2000	2010	2020	2030
Grand Forks	41,986	45,409	53,545	62,128	72,296	83,976	97,351
East Grand Forks	8,397	9,279	10,737	12,376	14,463	16,800	19,475

Table 6 summarizes the projected annual average water demands for the urban area. These projections are based on the above referenced residential, commercial, and major industrial water demands. The average day water demands will be used for sizing water supply sources and for operation and maintenance expenses.

Table 7 summarizes the projected maximum day water demands for the urban area. These projections are based on historical trends and could occur in either May, June, July, or August. For design purposes, it is assumed that the maximum day demand will occur in June when the agricultural processing industry demands are at their lowest level. These projections indicate that the maximum day to average day ratio in year 2000 would be 2.26 in Grand Forks and 2.65 in East Grand Forks for just the residential and commercial demands. These ratios are typical for communities similar in size to Grand Forks and East Grand Forks.

Table 6 - Projected average day urban water demands

	Annual Average (mgd)					
	1980	1990	2000	2010	2020	2030
Grand Forks:						
Residential & Commercial[1]	4.54	5.35	6.21	7.23	8.40	9.74
Major Industrial[2]	3.17	3.24	3.43	3.60	3.77	3.93
Subtotal	7.71	8.59	9.64	10.83	12.17	13.67
East Grand Forks:						
Residential & Commercial[1]	0.93	1.07	1.24	1.45	1.68	1.95
Major Industrial[2]	0.57	0.64	0.71	0.77	0.84	0.91
Subtotal	1.50	1.71	1.95	2.22	2.52	2.86
Total Public Supply from Surface Water[3]	9.21	10.30	11.59	13.05	14.69	16.53
Self-Supplied Industries Using Surface Water	0.63	0.63	0.63	0.63	0.63	0.63
Total Surface Water Demands (cfs)	9.84 (15.22)	10.93 (16.91)	12.22 (18.90)	13.68 (21.16)	15.32 (23.70)	17.16 (26.55)
Self-Supplied Industries Using Groundwater	0.15	0.15	0.15	0.15	0.15	0.15
Total Urban Water Demand	9.99	11.08	12.37	13.83	15.47	17.31

[1] Average day use is based on population projections times 100 gpcd. Includes water consumed by customers, unaccounted distribution system losses, and wasted filter backwash water.

[2] From table 5.

[3] Grand Forks plus East Grand Forks

Source: Stanley Consultants

Table 7 - Projected maximum day urban water demands

	Maximum Day (mgd)[1]					
	1980	1990	2000	2010	2020	2030
Grand Forks:						
Residential & Commercial[2]	11.06	12.40	14.04	15.92	18.05	20.46
Major Industrial[3]	2.20	2.37	2.54	2.71	2.88	3.05
Subtotal[4]	13.26	14.77	16.58	18.63	20.93	23.51
East Grand Forks:						
Residential & Commercial[2]	2.59	2.91	3.29	3.72	4.21	4.77
Major Industrial[3]	0.20	0.27	0.34	0.41	0.48	0.55
Subtotal[5]	2.79	3.18	3.63	4.13	4.69	5.32
Total Public Supply from Surface Water[6]	16.05	17.95	20.21	22.76	25.62	28.83
Self-Supplied Industries Using Surface Water	--	--	--	--	--	--
Total Surface Water Demands	16.05	17.95	20.21	22.76	25.62	28.83
(cfs)	(24.83)	(27.77)	(31.26)	(35.21)	(39.63)	(44.60)
Self-Supplied Industries Using Groundwater	--	--	--	--	--	--
Total Urban Water Demand	16.05	17.95	20.21	22.76	25.62	28.83

[1]Maximum day could occur in May, June, July, or August. The maximum day used for design is projected to occur in June when the major industrial users demands are low.

[2]Difference between Total City and Major Industrial.

[3]Estimated from 1976 and 1977-78 records and escalated for new industrial growth.

[4]Maximum day is based upon a ratio of total city average to maximum of 1.72.

[5]Maximum day is based upon a ratio of total city average to maximum of 1.86.

[6]Grand Forks plus East Grand Forks.

Source: Stanley Consultants

The maximum day demands listed in table 7 will be used to size water transmission and treatment facilities. It is assumed that the self-supplied industries will continue to supply their separate water needs. These industries utilize that water for sluicing, cooling, and other uses so a high degree of treatment before use is not needed. The water demands served by the city public water systems require a high quality water so extensive treatment is needed.

EXISTING WATER SYSTEM FACILITIES

GENERAL

Figure 4 locates the service areas of the municipal, Air Force Base, and rural water systems in the study area. All of the study area is under the jurisdiction of either a municipal or rural water service system. Many of the rural areas rely on private wells because of inadequate capacity or high costs for extending the existing rural systems. However, the stage 2 study determined that it was more cost-effective for the rural systems to expand their own service capability rather than become part of a regional system.

Grand Forks presently serves the city and the Grand Forks Air Force Base through a high service and a booster pumping system. East Grand Forks provides water service within its corporate boundaries.

URBAN WATER SYSTEM FACILITIES

Figure 5 outlines the existing water supply, treatment, and distribution facilities which serve the urban area.[6,9,10,11] The municipal systems of Grand Forks and East Grand Forks are interconnected, so treated water could be transferred between the cities. Under current arrangements, this transfer would occur only during an emergency condition which has not occurred to date.

Grand Forks Water System Facilities

Grand Forks obtains its water supply from the Red River of the North and the Red Lake River. A blend of both waters is proportioned to optimize treatment capabilities. Grand Forks has two raw water intakes on the Red River of the North with a 6.5-mgd (million gallons per day)

capacity at Intake No. 1 and 10.0-mgd capacity at Intake No. 2. The Grand Forks Red Lake River raw water intake (Intake No. 3) has an 8.9-mgd capacity. A low-head dam at Riverside Park pools water on the Red River of the North. This dam has recently been repaired and the repair is projected to extend its useful life through about 1990. Also, there is a low-head dam on the Red Lake River just upstream from its confluence with the Red River of the North. This low-head dam pools water for the Grand Forks Red Lake River intake and the East Grand Forks intake.

Figure 6 shows the flow diagram of the Grand Forks water treatment plant. This plant provides pretreatment, softening, filtration, and disinfection before distribution. In the pretreatment basin, alum, polymer, and powdered activated carbon are added for turbidity reduction and color, taste, and odor control. Lime, soda ash, sodium aluminate, and carbon dioxide are added to the two-stage softening, recarbonation, and stabilization processes to reduce the hardness of the water. Posttreatment includes the addition of chlorine for disinfection, fluoride, and a polyphosphate for stabilization. The current water treatment plant was originally built in 1958, was expanded in 1968, had multimedia added in 1976 to the 1958 plant, and had sludge handling processes installed in 1977. The sludge handling facilities include surge/clarifier, thickener, vacuum filters, wet wells, and trucking of the sludge to the city landfill. The sludge supernatant is recycled to the head end of the plant to eliminate discharges to the Red River of the North. The water treatment plant is operated on a 24-hour-per-day basis.

Hydraulic constraints limit the rated capacity of the Grand Forks water treatment plant to 12 mgd. The single media sand filter in the 1968 plant is limited to a hydraulic loading of 2 gpm (gallons per minute) per sq ft (square foot), while the multimedia filters in the 1958 plant can be loaded at a higher

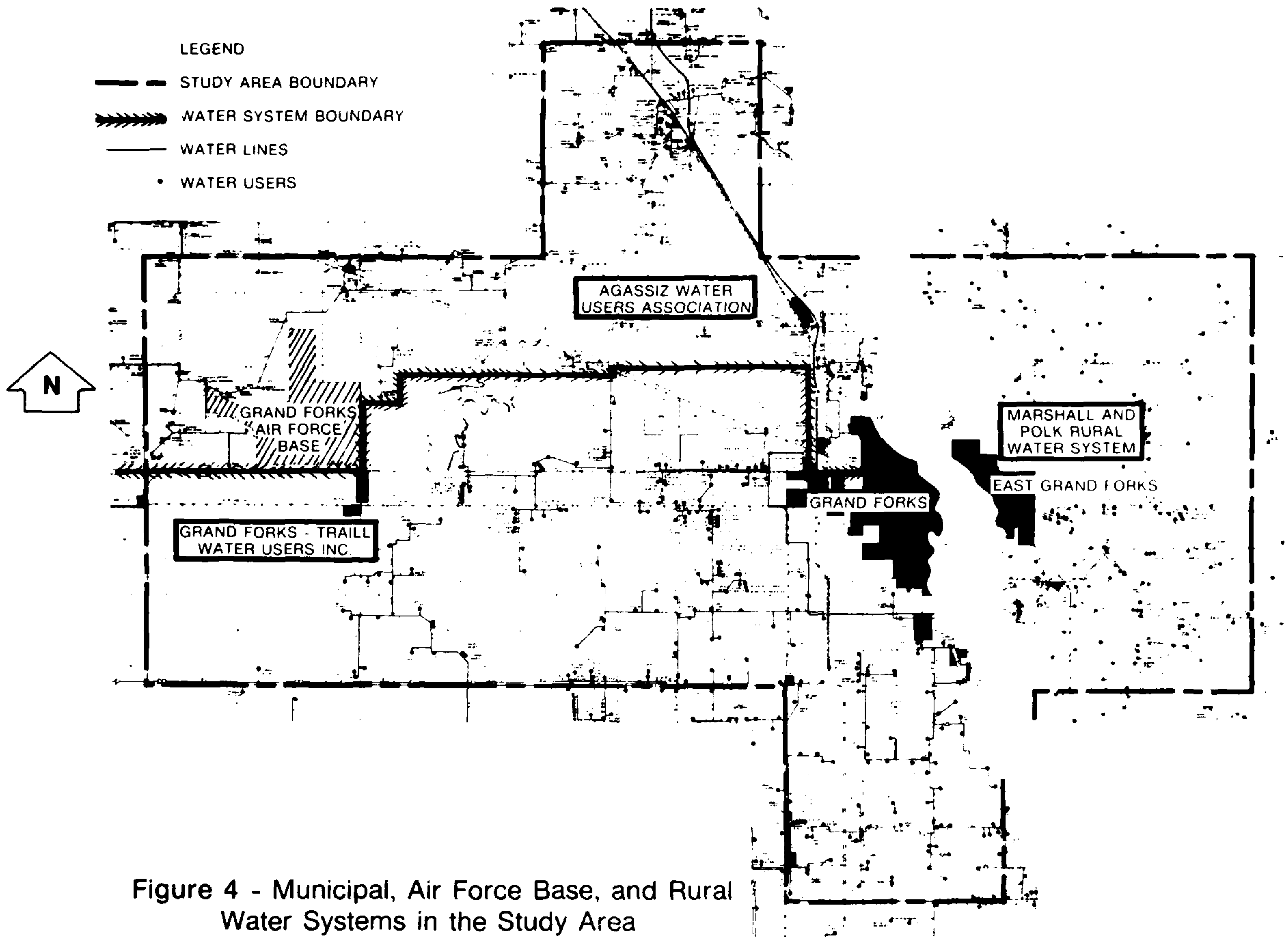


Figure 4 - Municipal, Air Force Base, and Rural Water Systems in the Study Area

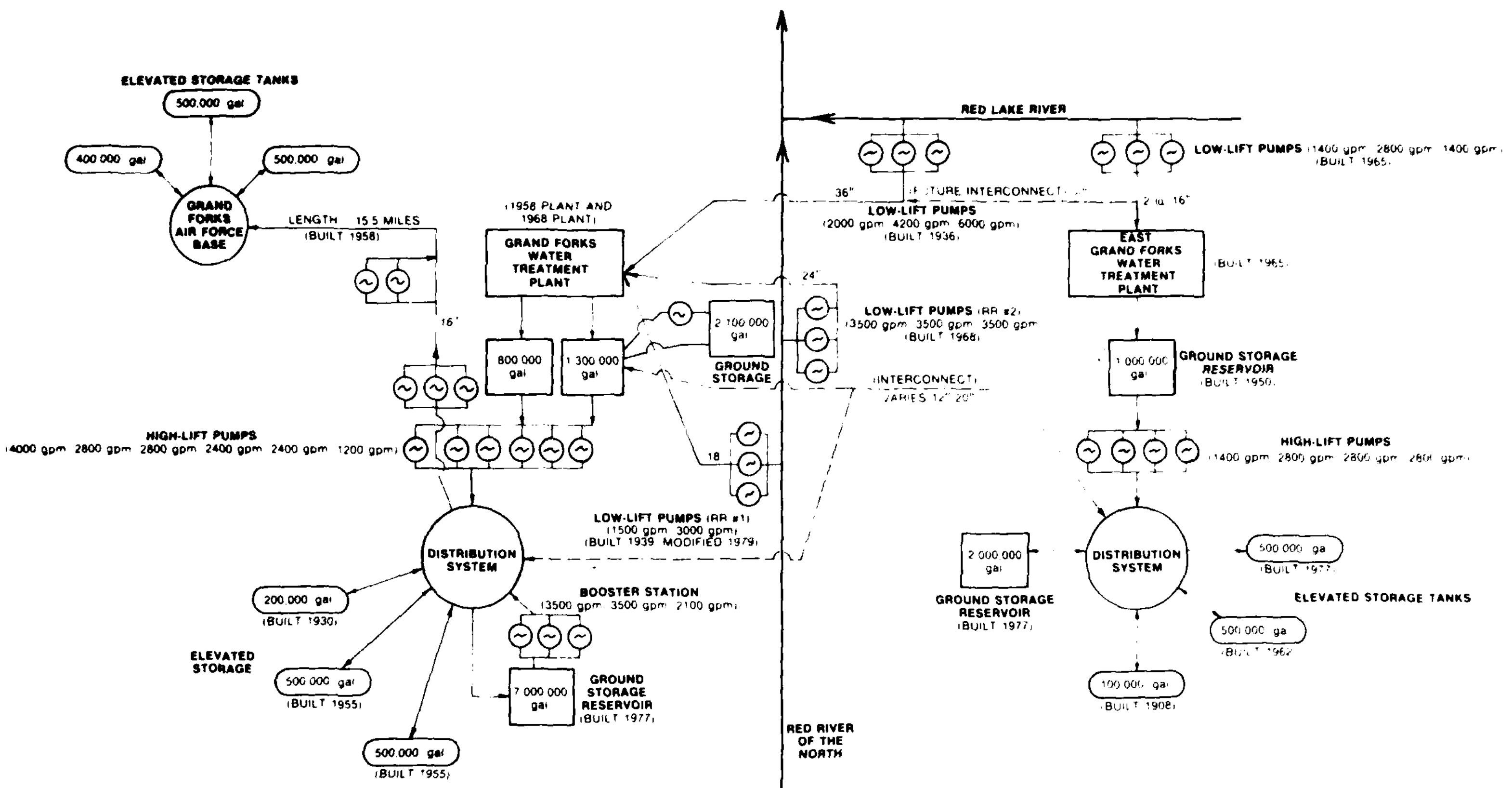


Figure 5 - Schematic of Existing Water System Facilities

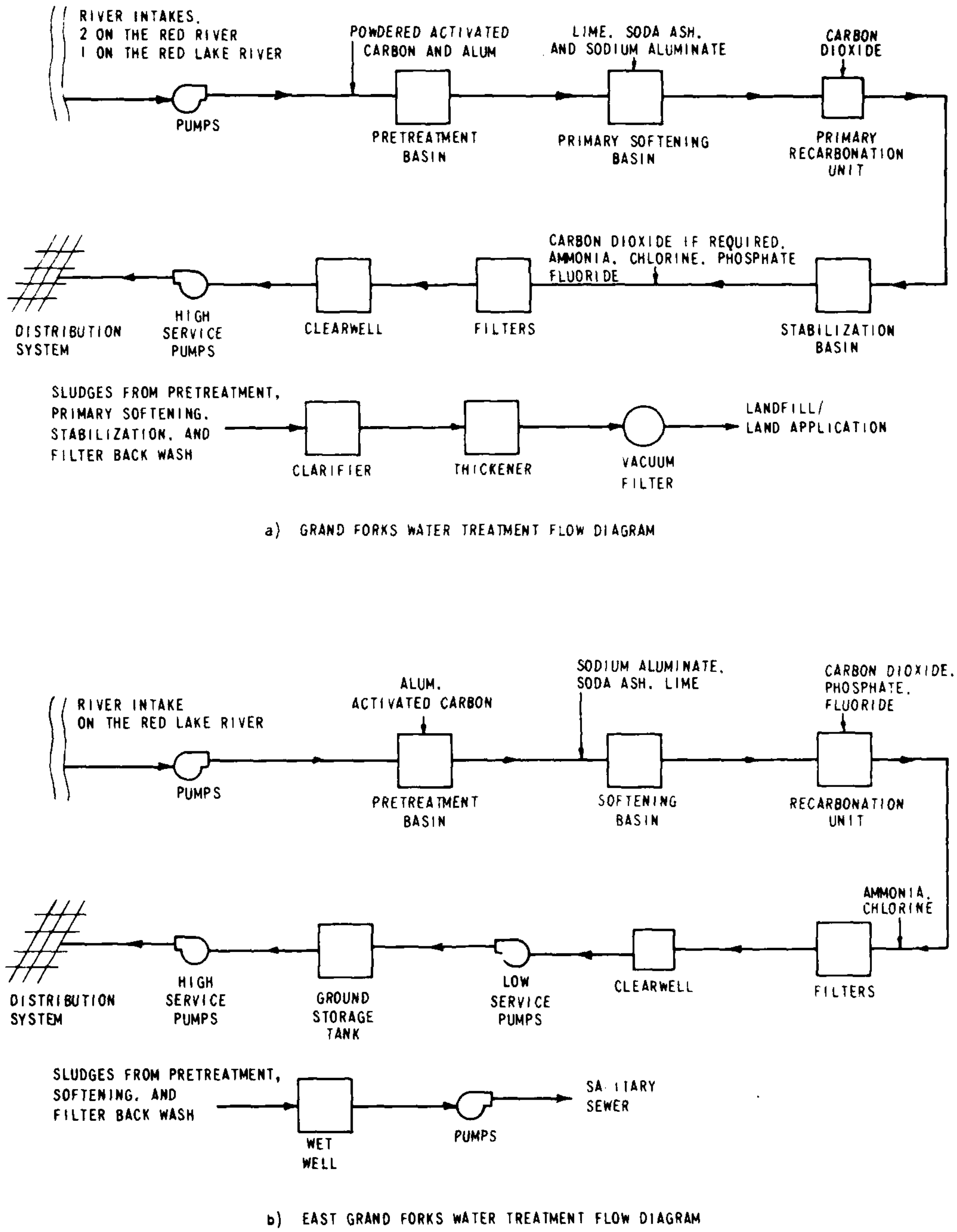


Figure 6 - Flow Diagrams of the Grand Forks and East Grand Forks Water Treatment Plants

rate. The North Dakota Department of Health will allow up to 5 gpm per sq ft on multimedia filters if pilot plant or other operational data show adequate treatment can be obtained. Water treatment facilities are sized to treat maximum day demands. The current maximum day demand experienced at Grand Forks is approximately 12.0 mgd.[5] Therefore, an expansion is needed to meet future demands. The land area at and/or near the existing plant site is limited. The existing plant is located near the downtown business district and is in a completely built-up area. A small area is available on the existing site, but a major expansion would require the purchase and removal of one or more blocks of residential housing or location at a new site.

The water transmission lines and treated water storage facilities are shown on figure 5. Grand Forks has recently installed a 7-million-gallon ground storage reservoir on the west side of the city. This brings the total city storage capacity to 12.4 million gallons. The Grand Forks Air Force Base has 1.4 million gallons of storage. There is presently only one water transmission line serving the Air Force Base. This line has experienced a number of breaks and leaks due to the action of corrosive soils on the cast iron pipe. A second transmission line from Grand Forks to the base would substantially increase the water supply reliability for the base.

East Grand Forks Water System Facilities

East Grand Forks obtains its water supply from the Red Lake River through a 4.0-mgd raw water intake. A low-head dam on the Red Lake River located just above its confluence with the Red River of the North pools water for the intake. There has been a proposal to construct an intake for East Grand Forks on the Red River of the North.[6] However, this project is not proceeding at this time.

Figure 6 shows the flow diagram of the East Grand Forks water treatment plant. Like the Grand Forks plant, this plant provides pretreatment, softening, filtration, and disinfection before distribution. However, because Red Lake River water is of better quality, one-stage softening is employed. In the pretreatment basin, alum and powdered activated carbon are added to reduce turbidity and to control color, taste, and odor. Lime, soda ash, sodium aluminate, and carbon dioxide are added to the softening and recarbonation processes to reduce the hardness of the water. Posttreatment includes chlorine for disinfection, fluoride, and a polyphosphate for stabilization. Sludge handling facilities include a pumping station and force main for pumping the filter backwash and softening sludges to the sanitary sewer. There is currently no discharge to the Red Lake River from the plant. The water treatment plant is operated 8 to 10 hours per day.

The East Grand Forks water treatment plant was built in 1962 and has a rated capacity of 4.0 mgd. When the flow rate exceeds 3.0 mgd, the plant experiences some difficulty in holding the softening basin sludge blanket.[10] The present maximum day demands are less than 3.0 mgd, so this operating difficulty has not been much of a problem and East Grand Forks is currently considering measures to correct this problem. Water treatment facilities are sized to treat maximum day demands. The current maximum day demand is projected to reach 4.0 mgd in about year 2005. The hours of operation at the plant will have to be increased to 24 hours per day by year 2005 to meet maximum day demands. There is undeveloped land area adjacent to the East Grand Forks plant which could be used for expansion.

The water transmission and storage facilities were shown on figure 5. East Grand Forks has recently completed construction of a 2-million-gallon storage reservoir and a 500,000-gallon elevated storage tank. These facilities bring the total city storage capacity to 4.1 million gallons.

OTHER WATER SYSTEMS IN THE STUDY AREA

Figure 4 shows the location of the three rural water systems operated by the Agassiz Water Users Association, the Grand Forks-Traill Water Users, Inc., and the Marshall and Polk Rural Water System.[2] Each system obtains its water supply from alluvial aquifers. Several industries and other users obtain nonpotable groundwater for various purposes from local aquifers. Also, some residential users (mainly rural) buy water from commercial water haulers who obtain the water from the city systems. As previously indicated, the Stage 2 Water Supply Study recommended that the rural water systems, the self-supplied industries, and other self-supplied users continue to supply their own needs rather than join a regional urban water system.

ADEQUACY OF EXISTING WATER SYSTEM FACILITIES

The above review indicates that several improvements to the water supply and treatment facilities will be required in the near or relatively near future. These improvements include the following:

1. For Grand Forks, expansion of the existing water treatment capacity to serve future demand. This expansion is needed immediately. Land area at and/or near the existing plant is limited.
2. For the Grand Forks Air Force Base, installation of a second water transmission line from Grand Forks to the base for increased reliability.
3. For Grand Forks, East Grand Forks, and the Air Force Base, replacement and maintenance of existing facilities such as water intakes, transmission lines, treatment facilities, and distribution systems.
4. For East Grand Forks, modification or adjustment of the existing water treatment plant to ensure that it can treat 4.0 mgd.
5. For Grand Forks, replacement of the low-head dam near Riverside Park which pools water on the Red River

of the North. This improvement is required in about 1990.

6. For East Grand Forks, construction of a water intake structure to obtain water from the Red River of the North.
7. For East Grand Forks, increase in the hours of operation as the demands increase and expansion of the existing water treatment plant when its capacity is exceeded.
8. For Grand Forks and East Grand Forks, expansion of water treatment facilities when their capacity is exceeded.

WATER SUPPLY SOURCE ALTERNATIVES

GENERAL

This section summarizes the water supply sources available to the urban area and, as recommended in the Stage 2 Water Supply Study, considers the following sources in more detail:

1. Red River of the North and Red Lake River surface water supplies including in-channel and/or off-channel storage reservoirs.
2. Garrison Diversion water to supplement the Red River of the North flow.
3. Elk Valley aquifer groundwater supply.
4. Water conservation measures.

Water conservation measures are techniques for reducing maximum and average daily demands. Therefore, the potential surface and groundwater sources can more easily supply water demands in the urban area. In addition to the Elk Valley aquifer, the Beach Ridge aquifers in Minnesota are considered as a potential groundwater supply source.

A water supply source should be capable of supplying an adequate quantity of raw water which can be easily treated. When raw water storage facilities are not provided, the source should be capable of supplying maximum day demands. With raw water storage, the source should be capable of supplying average day demands. Raw water may be stored in-channel, off-channel, or in an aquifer.

A relatively good quality water can be more easily treated and therefore minimizes costs, simplifies operation, and increases

the reliability that a high quality water will be delivered to the distribution system. A very hard or highly saline water is more expensive and difficult to treat. The water quality standards which must be satisfied are discussed in the next section of this report.

As indicated in the previous section, surface water sources currently supply the urban area water demands. Grand Forks has two water intakes in the Red River of the North and one in the Red Lake River. East Grand Forks has only one water intake in the Red Lake River. A low-head dam located on each river pools water for the city and self-supplied industry intakes.

SURFACE WATER SOURCES

Figure 7 displays the surface water resources which are available to the urban area. The Red River of the North and the Red Lake River currently supply most of the water demands in the area. These rivers are the only significant surface water sources capable of supplying the urban area water demands.

A review of previously available data indicates that existing data and studies do not adequately define the quantity of surface water available to supply the urban area water demands. Previous studies used data and technologies that were available at the time of those studies. More advanced technologies have been developed and reservoirs now regulate flows on the Red River of the North and the Red Lake River. These reservoirs were constructed in the early 1950's and have significantly changed the streamflow characteristics. Therefore, historical USGS (U.S. Geological Survey) stream gaging records are not adequate to define future low-flow conditions. The three multipurpose reservoirs used for low-flow augmentation are:

1. Red Lakes Reservoir on the Red Lake River, Minnesota. The initial control structure was built in 1931, and

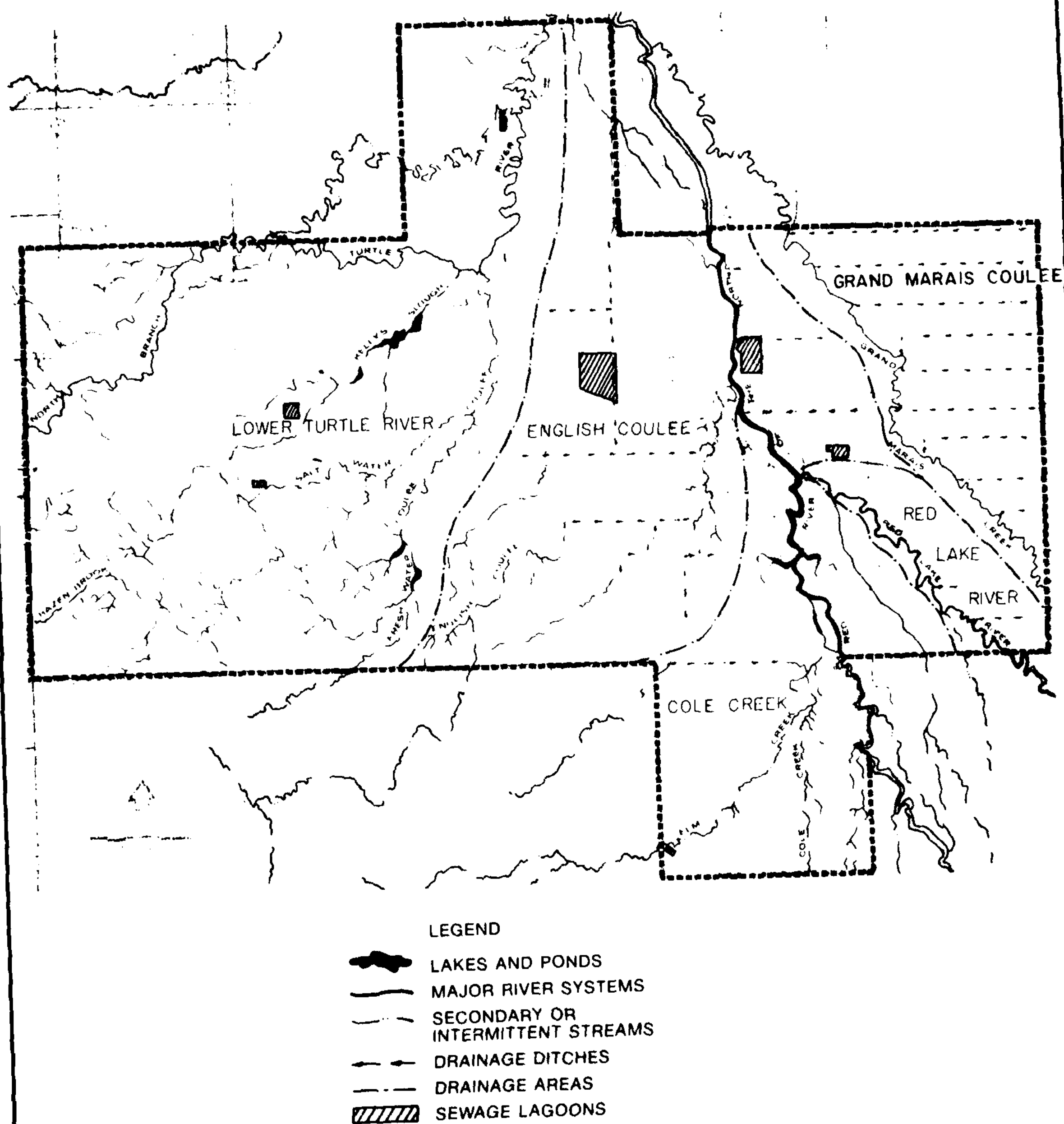


Figure 7 - Surface Water Resources

that structure was replaced by the existing control structure completed in 1952.

2. Orwell Reservoir on the Otter Tail River, Minnesota. Completed in 1953.

3. Lake Ashtabula (Baldhill Dam) on the Sheyenne River, North Dakota. Completed in 1950.

A detailed low-flow frequency analysis was conducted as part of this study.[12] That analysis statistically analyzed the simulated low-flow events that are projected to occur in the Red River of the North at Grand Forks and the Red Lake River at East Grand Forks. The objective of the analysis was to define the availability of surface water and the need for supplemental in- and/or off-channel storage.

A secondary objective was to determine when supplemental storage or an offsetting reduction of water demands becomes necessary. For this objective, the year when projected water demands first reach a level necessitating supplemental water supply storage to cope with a 50-year return drought is estimated. The design drought for this water supply study has been established as the 50-year recurrence event. However, there was peripheral interest in the 100-year event to determine if the latter's relative severity and preventive costs greatly exceed those of the 50-year event.

The low-flow condition analyzed was the year 2030 water demands and existing reservoir operation. The input data for the low-flow frequency analysis were provided by the St. Paul District of the Corps of Engineers. These data were generated by the Hydrologic Engineering Center HEC-3 computer program, "Reservoir System Analysis for Conservation."[13] This program simulated monthly average flows for the homogeneous period of record from 1930 to 1976. The HEC-3 program and simulations are also being used by the Corps for its overall Red River of the North Basin Study.[14]

The frequency-mass curve analysis procedure was used to analyze the simulated monthly flows. This procedure involves two steps. First, low-flow frequency curves are computed by sequential analysis of the minimum average flows for various durations. Then, a mass curve is constructed for the specified design frequency. This procedure is commonly used in the field and is widely accepted. The results obtained were checked and verified by several other computational analyses.[12]

A family of low-flow frequency curves was derived from the HEC-3 simulated monthly flows by using the HEC program entitled "Partial Duration - Independent Low Flow Events."[15] This program analyzes flows of any given duration throughout the period of record. These flows are arranged in ascending order of magnitude (smallest first) and statistically analyzed. The return frequency for each flow duration is computed by the Beard's Method.[16] This HEC program is satisfactory for developing discharge-frequency curves for durations between 2 months and 12 months. To supplement the HEC's partial duration analyses, discharge-frequency curves for durations of 7 days, 14 days, 1 month, 24 months, 48 months, and 96 months were computed by other procedures.[12]

The partial duration analyses and adjustments result in a family of low-flow discharge-frequency-duration curves. These curves are used to develop mass curves of the streamflow that is available for water supply. Mass curves are composites of flow for all durations for a specified design frequency and are assumed to constitute enveloping conditions of a "design" low-flow hydrograph. The urban area water demands are superimposed on the mass curve and the point of maximum divergence between the average draft rate and the mass curve yields the reservoir storage requirement for a "design" frequency. It is common practice to increase storage requirements obtained by this method by 10 percent.[17,18]

The HEC-3 program Run #16 was used for the low-flow frequency analysis. Run #16 predicted that the Red River of the North could not satisfy combined Grand Forks and East Grand Forks year 2030 water demands during August 1936 simulated flows. The Red Lake River could not satisfy East Grand Forks year 2030 water demands during simulated August and September 1936 conditions. These 1- and 2-month water shortages result because the water level in the Red Lakes Reservoir fell below its designated minimum conservation pool. At this point, the discharge is reduced from an average rate of 50-cfs to 15-cfs maximum discharge. These discharges are specified by the provisions of a treaty with the Red Lake Band of the Chippewa Indians. These shortages are reflected in the partial duration analysis.

The extreme low-flow events that occurred during the 1930's are within the 47-year period of record (1930 to 1976) analyzed by the HEC-3 program. Based on the partial duration analysis and Beard's plotting method, the extreme events have a recurrence frequency of 67.0 to 68.2 years for durations of 12 months or less. However, discussion with Corps personnel indicates that a longer recurrence frequency should be assigned to the extreme events. This conclusion is based on analyses performed by the Corps. The Corps used its HEC-4 computer program "Monthly Streamflow Simulation" to stochastically extend the 40 years of streamflow data.[19] Four hundred years of synthetic data were generated. However, the 1930's drought could not be reproduced. Reasons given were: there was no long-term buildup to the 1930's drought and the extreme duration of the drought prevented the regression analysis from simulating the extreme low-flow events. Other computational analyses indicate that there are two statistical "populations" of streamflow. The first occupies almost the entire range of normal flows and for which there is abundant data to establish frequency distribution data. The second "population" extends

through the range of low flows when low-flow augmentation effects from upstream reservoirs become significant. This lower range of flows requires a different model for generating synthetic flows because few data points are available. The synthetic extension of historical data would be applicable in some cases, but should not be used for this area until a more sophisticated model can be derived.[12]

The extreme low-flow events must still be assigned a recurrence frequency. The USGS studied the frequency of low-flow events on the Red River of the North in a 1962 report.[20] That report concluded that, although evidence may not be adequate to warrant assignment of a definite recurrence interval to the minimum flows of the 1930's, the minimums were probably the lowest that occurred during a period of at least 150 years.

Therefore, discussion with Corps personnel concluded that the extreme low-flow events defined by the partial duration analysis would be assigned a conservative value of a 200-year recurrence interval.[21] The discharge-frequency-duration curves were extended in response to this adjustment.

Figure 8 shows the results of the partial duration analysis for the Red River of the North at Grand Forks. The family of low-flow discharge-frequency-duration curves for 7 days through 8 years is presented. These curves represent the average flow rates available to satisfy Grand Forks and East Grand Forks projected year 2030 water demands. These curves also indicate that the basin reservoirs have a significant effect on streamflow. At recurrence intervals greater than 10 to 20 years, reservoir low-flow augmentation releases maintain higher flows than have historically been observed; thus, the "S" curve shape. Discontinuities in the spacing between curves are probably due to the way the HEC-3 program releases flow from the reservoirs. During dry

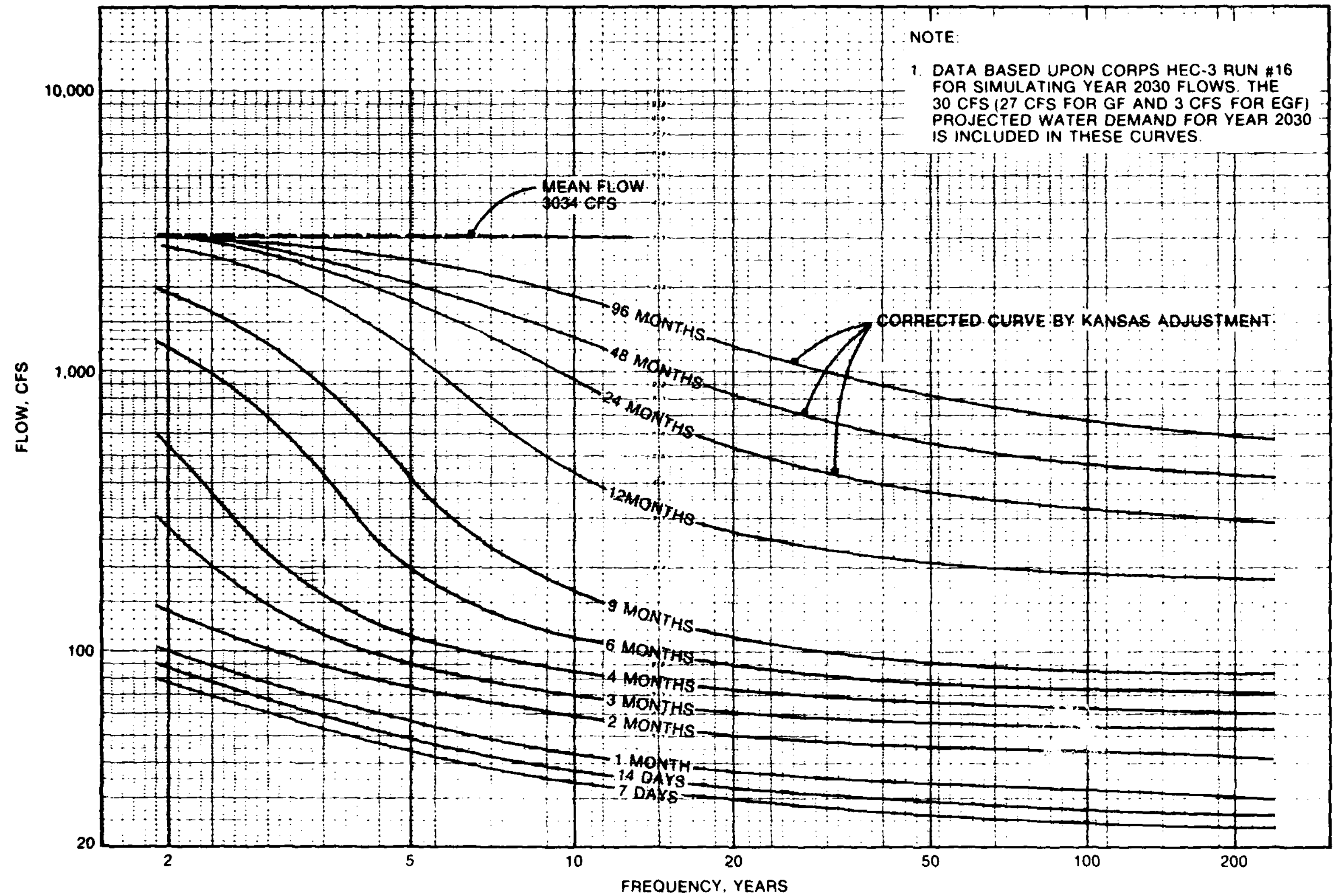


Figure 8 - Low-Flow Frequency Curves, Red River of the North at Grand Forks

periods, the minimum allowable flows are released, but, during wet periods, the maximum flow quantities are released. For example, a dry period of 9 months followed by spring runoff would produce a significant difference between the 9-month and longer duration curves.

Figure 9 presents the family of low-flow discharge-frequency-duration curves for the Red Lake River at East Grand Forks. These curves reflect the average flow rates available to satisfy East Grand Forks projected year 2030 water demands. There are not enough data to guide the extension of the curves beyond a 20-year recurrence frequency. The Red Lakes Reservoir has a significant impact on the river flows due to its low-flow augmentation. Therefore, extrapolation of the curves from the 20-year to 200-year recurrence frequencies cannot rely on the shape of the curves between recurrence frequencies from 2 years to 20 years. Also, the Red Lakes Reservoir operates to satisfy water demands and minimum downstream flows (3 cfs passing East Grand Forks and 8 cfs passing Grand Forks), which tends to weight low flows toward the 3- and 8-cfs flows.

Figure 10 presents the mass curves for the Red River of the North at Grand Forks. The mass curves for 20-year, 50-year, and 100-year recurrences are shown. The mass curves were obtained from the family of discharge-frequency-duration curves by multiplying the average flow rate times the duration in days to obtain cfs-days. These quantities were adjusted to allow the minimum 8 cfs to pass below Grand Forks. The cumulative flow is shown only through about 6 months because the quantity of streamflow exceeds the cumulative water demand. The control point on the Red River of the North at Grand Forks includes the Red Lakes River and is below the water intakes of Grand Forks, East Grand Forks, and self-supplied industries. All urban area surface water demands and supplies are included in this control point.

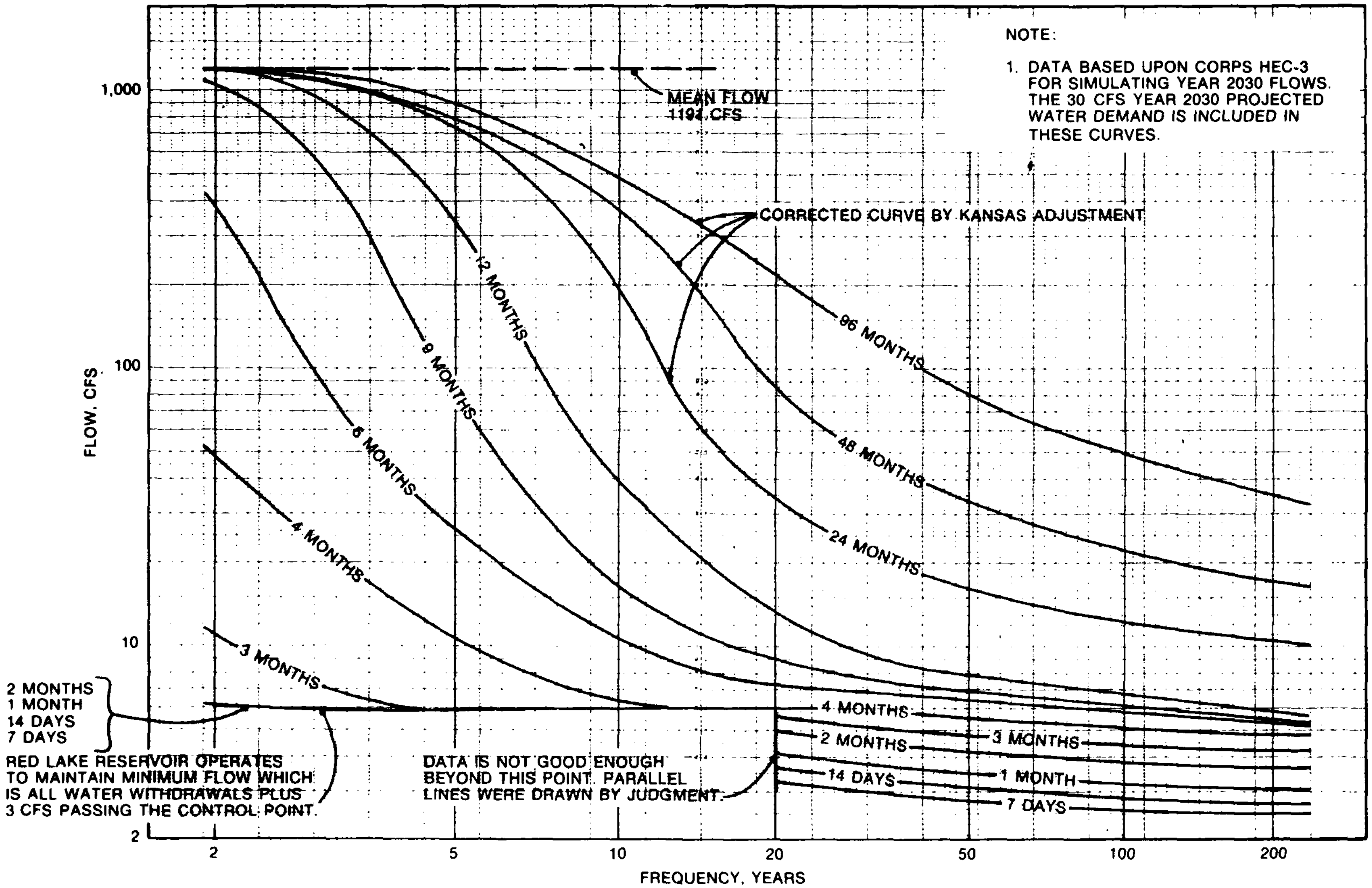


Figure 9 - Low-Flow Frequency Curves, Red Lake River at East Grand Forks

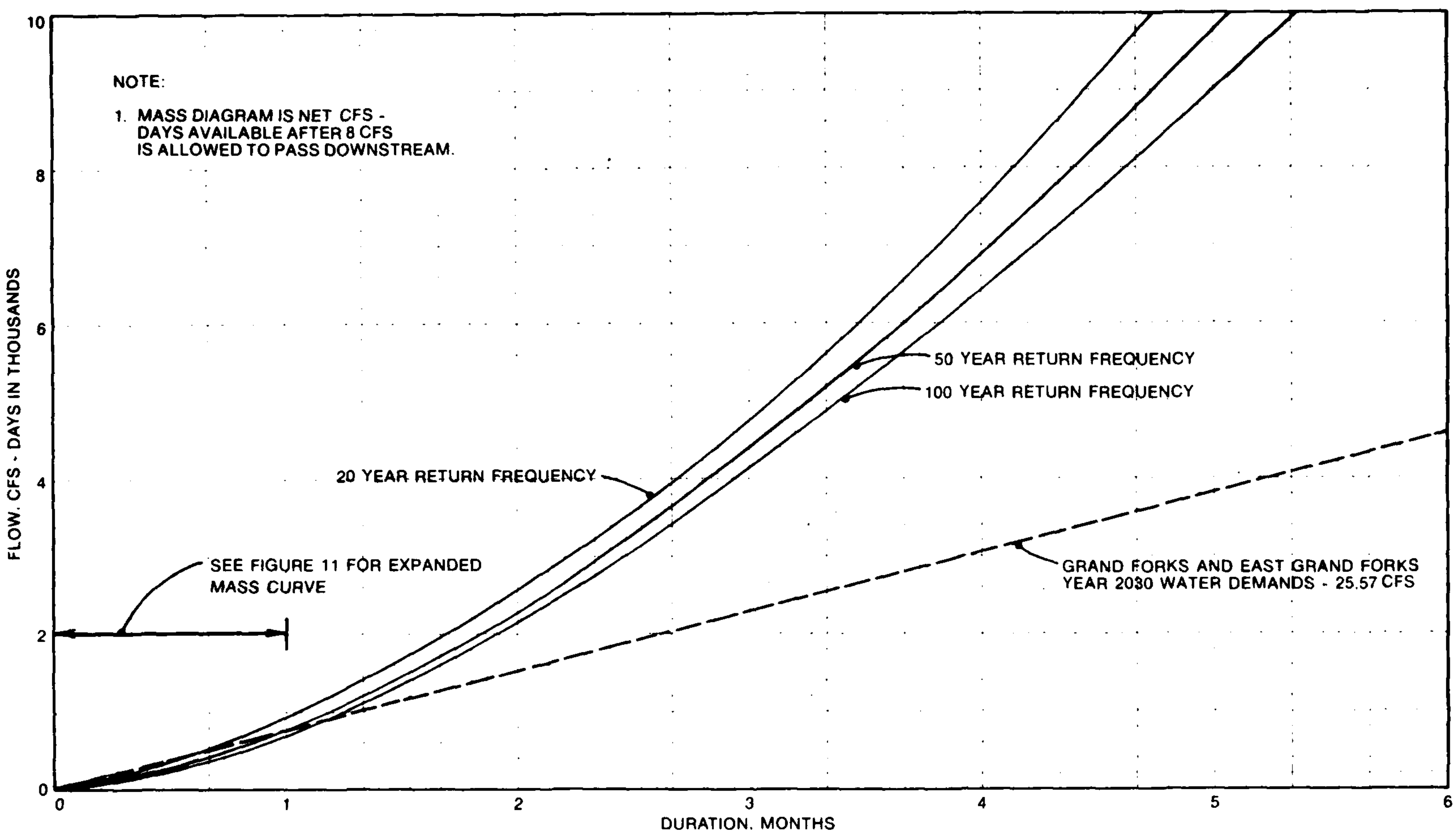


Figure 10 - Mass Curve for the Red River of the North at Grand Forks

Figure 11 is a blow-up of the 1-month period shown on figure 10. The Grand Forks and East Grand Forks year 2030 water demand curve is superimposed on the streamflow mass curves. The maximum divergences between demand and streamflow curves are the net quantities of supplemental water supply storage required. An allowance of 10 percent is added in accordance with the frequency-mass curve analysis procedure.

The HEC-3 program simulates streamflows but does not account for evaporation losses associated with in- and/or off-channel storage volumes. Evaporation losses are based on an evaporation of 28 inches per year and are estimated to be about 5.6 inches in one month and about 34.5 inches in 450 days.[4] Storage lost to evaporation depends on the reservoir surface area. In-channel storage has a relatively large surface area because the river slopes are relatively flat. Off-channel reservoirs store only the quantity of water needed so the surface area is minimized.

Figure 11 indicates that water supply shortages would be experienced for approximately 30 days during a 50-year drought event. Flows from both the Red River of the North and the Red Lake River are used to satisfy Grand Forks and East Grand Forks water demands. The storage requirements for various drought return frequencies are as follows:

Drought Return Frequency (years)	In-Channel Storage: Base Storage Required (ac-ft)	In-Channel Storage: Evaporation Duration (days)	In-Channel Storage: Evaporation Loss (ac-ft)	In-Channel Storage: Total Storage Required (ac-ft)
20	60	17	180	240
50	130	29	370	500
100	180	35	450	630

In-channel storage surface areas pooled behind the low-head dams are about 600 acres on the Red River of the North and 200 acres on the Red Lake River.

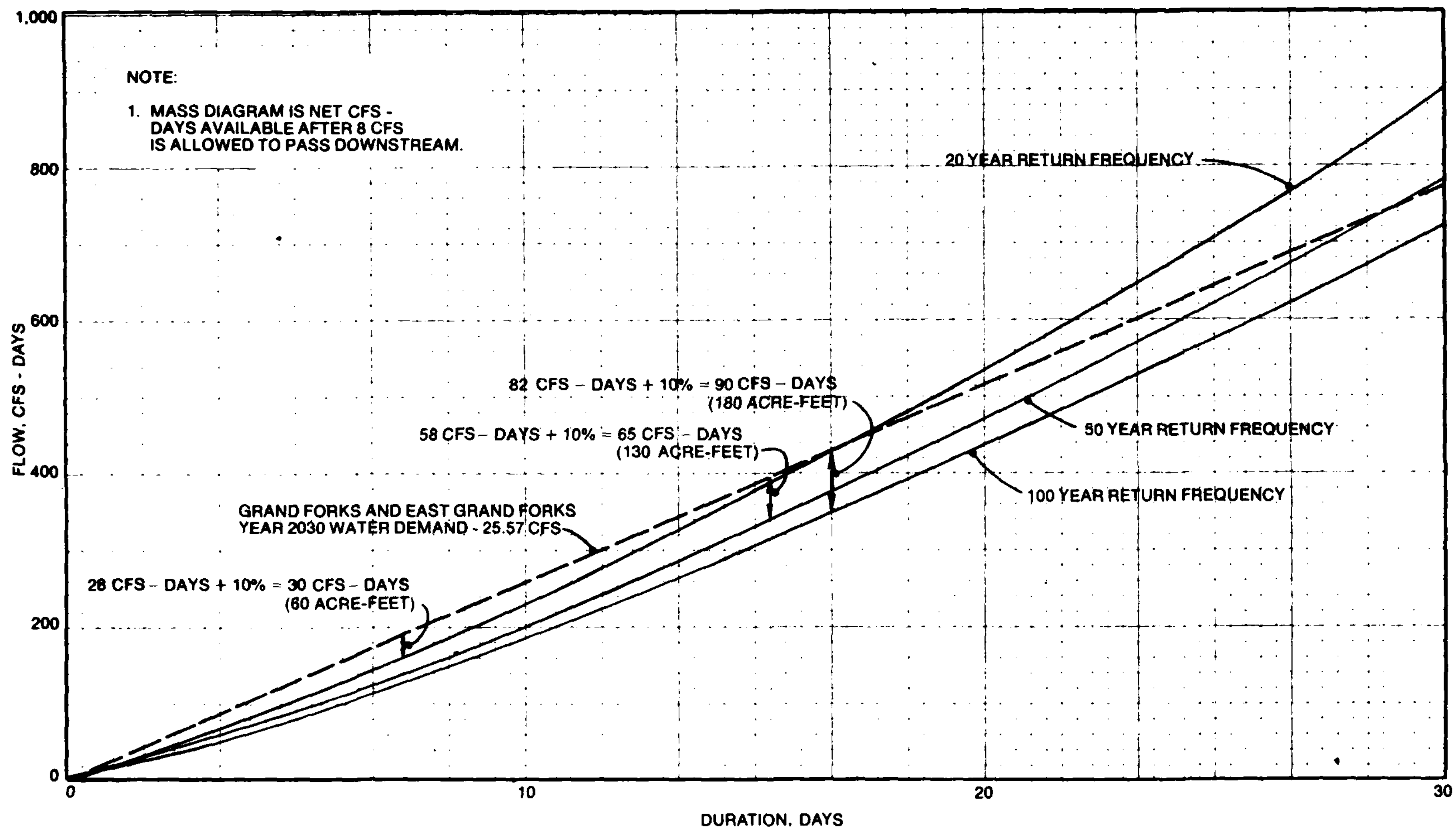


Figure 11 - One Month Duration Mass Curve for the Red River of the North at Grand Forks

Off-channel storage reservoirs were also considered. Evaporation adds about 1.3 acre-feet of storage based on 17 days duration, 5 acres of surface area, and a 15-foot working depth in the reservoir. For 35 days duration, evaporation adds about 7.3 acre-feet of storage to the base storage required. The added storage is based on 15 acres of surface area and a 15-foot working depth.

Figure 12 presents the mass curves for the Red Lake River at East Grand Forks. The mass curves for 20-year, 50-year, and 100-year return frequencies are shown and include the adjustment for the minimum of 3 cfs that must be allowed to pass below East Grand Forks. Water supply shortages would be experienced based on year 2030 projected water demands. Shortages occur for two reasons:

1. There are periods when the projected water level in the Red Lakes Reservoir falls below the minimum conservation pool.
2. The year 2030 projected water demand is 2.86 mgd (4.42 cfs) rather than 3 cfs as used in the HEC-2 model.

The Red Lakes Reservoir can at most times operate to satisfy the 4.42-cfs demand, but, for the 2 months when the reservoir level is below the minimum conservation pool, storage would still be needed. Storage would also be required at a 3-cfs demand, but the duration and magnitude of the shortage would be decreased.

Based on Figure 12, the water shortages and the volume of storage required to satisfy East Grand Forks demands during various drought return frequencies are as follows:

Drought Return Frequency (years)	In-Channel Storage			
	Base Storage Required (ac-ft)	Evaporation Duration (days)	Evaporation Loss (ac-ft)	Total Storage Required (ac-ft)
20	380	186	420	800
50	520	270	450	970
100	720	450	610	1,330

Evaporation losses are based on the Red Lake River storage pool only. The in-channel storage surface area is about 200 acres. If off-channel storage reservoirs are used, evaporation losses add about 60 acre-feet of storage based on 180 days duration, 30 acres of surface area, and a 15-foot working depth. For 450 days duration, evaporation adds about 150 acre-feet of storage based on 50 acres of surface area and a 15-foot working depth.

The available in-channel storage pooled behind the existing low-head dams on the Red River of the North and the Red Lake River is estimated as follows:

	In-Channel Storage Volume (ac-ft)
Red River of the North	2,200
Red Lake River	1,000
TOTAL	3,200

All readily available sources have been used for this estimate. Cross sections and thalweg elevations surveyed in 1944, 1972, and 1979 indicate that the river channel elevations have not varied greatly with time.[22,23,24,25] Evidently, the river pools have stabilized, and the accumulated sediment is scoured by high flows. The pools behind the dams extend for a considerable distance because of the extremely flat channel slopes in the area. The river bottom slopes through the Grand Forks and East Grand Forks area are reported to be 0.4 foot per mile for the Red River of the North and 1.6-foot per mile for the Red Lake River.[2,22,24] At 0.4 foot per mile and an average water depth of 15 feet at the low-head dam, the Red River of the North pool extends 37.5 miles upstream. The Red Lake River pool extends about 10.6 miles upstream based on the 1.6-foot-per-mile slope and a water depth of 17 feet. This water depth is greater than that in the Red River of the North because the low-head dam crest elevation is 796.8

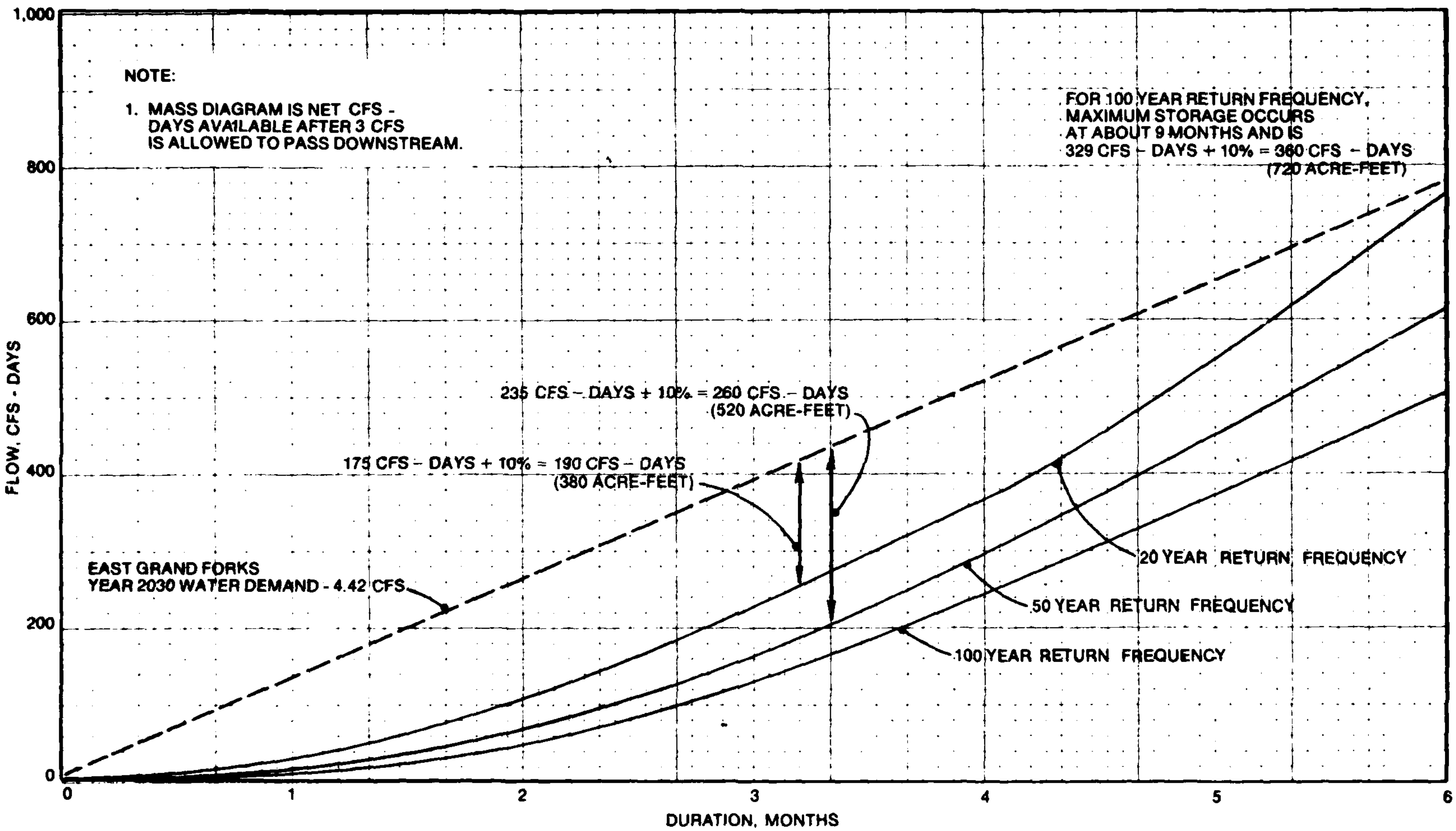


Figure 12 - Mass Curve for the Red Lake River at East Grand Forks

feet versus the Red River of the North low-head dam elevation of 794.3 feet. An allowance of 5 feet for sediment buildup between high-flow scours has been included in the estimated storage volumes.

The above analysis indicates that the combined Red River of the North and Red Lake River flows plus their in-channel storage can satisfy Grand Forks and East Grand Forks urban area projected water demands through year 2030. In-channel storage exceeds the required supplemental storage for the 50-year design drought and for droughts with at least the 100-year return frequency. Therefore, no additional off-channel storage is recommended. Continued maintenance and/or replacement of the low-head dams is important for maintaining in-channel storage capacity.

For the Red Lake River serving just East Grand Forks, river flow and in-channel storage can satisfy East Grand Forks projected water demands through year 2030 for up to the 50-year return frequency drought. To satisfy the 100-year drought, 330 acre-feet of off-channel storage would be required. Total land area for water storage, dikes, and access is estimated to be about 60 acres. East Grand Forks could satisfy these supplemental storage needs by constructing a backup water intake in the Red River of the North. More detailed analyses would be required to determine the most feasible and cost-effective solution. However, since the design drought is the 50-year recurrence event, no off-channel supplemental storage is recommended.

The Corps has operated the HEC-3 model for various water demand and reservoir discharge conditions. The range of water demands included projected usages for existing, 1980, 1990, 2000, and 2030. In general, changing water demands have minor impact on the streamflow at Grand Forks and East Grand Forks. One period of shortage still occurs because the water level in the Red Lakes Reservoir falls below its minimum conservation pool and water

releases are reduced from 50 cfs to 15 cfs. The magnitude of the shortage increases with increased water demands.

The water demand curves drawn on figures 10, 11, and 12 show this effect. On figure 12, if the water demand was 3 cfs rather than 4.42 cfs, the base supplemental storage requirements for the 50-year drought would be about 240 acre-feet for 150 days duration rather than 520 acre-feet for 270 days duration. However, the shortage still occurs and supplemental storage is required.

The evaporation losses over the 450-square mile surface area of the Red Lakes Reservoir have a significant impact on the streamflows. Run #17 operated the Red Lakes Reservoir to discharge 50 cfs rather than 15 cfs when the operating level fell below the minimum conservation pool. All water demands could be satisfied and no shortages resulted. Releasing 50 cfs did not significantly affect the water level in the Red Lakes Reservoir. This indicates that evaporation has a more significant impact on this reservoir than water demands.

The above summaries indicate that the low-flow augmentation reservoirs built and improved in the early 1950's can maintain streamflows except during extreme drought periods. During extreme drought periods, in-channel storage supplements natural streamflows to supply the urban area water demands. In-channel storage capacity is adequate when the combined Red River of the North at Grand Forks control point is considered and up to the 50-year drought when just the Red Lake River serving East Grand Forks is considered. Since the design criteria call for satisfying water demands during the 50-year drought, no additional off-channel storage is required. Also, East Grand Forks could improve the reliability of its water supply source by constructing a backup water intake in the Red River of the North.

For projected year 2030 water demands, the low-flow frequency analysis indicates that supplemental storage is required for all

droughts that have a return frequency greater than about 10 years. Thus, without in-channel storage, a water supply shortage would be experienced every 10 years (on the average).

Partial duration analyses for projected 1980, 1990, and 2000 water demands and modified reservoir operations were not conducted because available in-channel storage can satisfy the worst case conditions. However, by observation, supplemental storage would be required even for 1980 demands. When the Red Lakes Reservoir releases are reduced from 50 to 15 cfs, essentially none of the released flow reaches the urban area. Also, by observation, as water demands become smaller or more water is released from upstream reservoirs, the duration and magnitude of the shortage and, therefore, the required supplemental storage volume become smaller.

Since the in-channel storage capacity exceeds the required supplemental storage, no off-channel storage is required. However, because the low-head dams maintain the in-channel storage and pool water for the water intakes of Grand Forks, East Grand Forks, and self-supplied industries, it is recommended that the low-head dams be properly maintained and replaced when necessary. Also, because the Red Lake River in-channel storage is relatively small, East Grand Forks could improve the reliability of its water supply source by constructing a backup intake in the Red River of the North.

Table 8 summarizes the quality of the surface water in the Red River of the North and the Red Lake River. The data were collected between 1953 and 1977.[27,28] The average and range of the chemical constituents from all samples collected are presented. The two rivers exhibit similar water quality characteristics. The Red River of the North has higher total dissolved solids, hardness, and alkalinity and exhibits a greater extreme in suspended solids concentrations. Total dissolved solids concentrations

Table 8 - Surface water quality

Constituent	Red Lake River[1] Average[3]	Red Lake River[1] Range	Red River of the North[2] Average[3]	Red River of the North[2] Range
Physical				
Flow (cfs)	779	75-6,530	1,562	310-5,470
Turbidity[4] (JTU)	66	2-4,500	64	2-1,500
Color[5] (units)	30	5-100	29	5-120
Total Solids[5] (mg/l)	330	28-1,500	524	260-1,100
Suspended Solids (mg/l)	49	1-410	77	1-750
pH (units)	7.9	6.8-9.0	8.0	7.0-8.9
Biological				
Coliform Organisms[4] (#/100 ml)	5,546	20-92,000	2,462	20-160,000
Fecal Coliform (#/100 ml)	943	20-23,000	152	20-4,900
Fecal Strep (#/100 ml)	760	10-6,700	158	9-800
Chemical				
Alkalinity (mg/l as $CaCO_3$)	174	88-290	234	96-460
Hardness (mg/l as $CaCO_3$)	202	130-300	300	140-530
Calcium (mg/l as $CaCO_3$)	125	87-200	157	89-310
Magnesium (mg/l as $CaCO_3$)	65	40-90	146	91-250
Sodium (mg/l)	6.4	3-17	29.7	4-150
Potassium (mg/l)	3.8	1-29	6.8	2-20
Arsenic[4] (mg/l)	0.009	.001-.010	0.010	.001-.023
Barium[4] (mg/l)	0.024	.012-.050	0.024	.012-.050
Boron (mg/l)	0.048	.020-.070	0.110	.080-.180
Cadmium[4] (mg/l)	0.013	.010-.210	0.010	.010-.012
Chromium[4] (mg/l)	0.011	.002-.020	0.012	.002-.020
Chloride[5] (mg/l)	4.8	0.5-18.0	19.3	1.5-120.0
Copper[5] (mg/l)	0.012	.010-.060	0.012	.010-.040
Iron[5] (mg/l)	1.29	.010-17.0	1.84	.04-18.0
Lead[4] (mg/l)	0.013	.010-.130	0.018	.010-.420
Manganese[5] (mg/l)	0.100	.010-.640	0.132	.006-1.20
Mercury[4] (mg/l)	0.0002	.0001-.0008	0.0004	.0001-.0025
Nitrate[4] (mg/l)	0.23	.01-2.50	0.50	.02-4.70
Selenium[4] (mg/l as N)	0.006	.001-.010	0.006	.001-.010
Silver[4] (mg/l)	0.004	.002-.010	0.005	.002-.010
Sulfate[5] (mg/l)	28.0	9-81	106.0	29-260
Zinc[5] (mg/l)	0.063	.010-2.8	0.031	.010-.270

[1]At bridge on State Highway 220 at East Grand Forks.

[2]At Grand Forks Waterworks Intake.

[3]Average values when sampled or average value of samples.

[4]Limited in National Primary Drinking Water Regulations.

[5]Limited in National Secondary Drinking Water Regulations.

Source: Reference 28

follow a seasonal pattern and tend to be low during periods of high flow and high during periods of low flow.[29] The Red Lake River experiences higher average biological organism concentrations and, at low flow, the concentration of total dissolved solids and hardness greatly exceeds average values.[2]

Both rivers experience extensive periods of high turbidity. This is mainly due to the very fine silty clay stream beds. Fluctuating river levels and currents cause turbulence which resuspends colloidal clay particles. Also, runoff from agricultural land contributes to the suspended solids levels. Suspended solids concentrations also tend to be lower during periods of low flow and higher during high flows.[30,31]

Water treatment plant operators in Grand Forks indicate that the Red Lake River water is a little easier to treat because of its normally lower hardness levels. Both the Grand Forks and East Grand Forks water treatment plants remove suspended solids, color, taste, odor, and hardness. Higher dosages of chemicals are required during high flows to remove suspended solids and taste and odor problems. During low flows, higher chemical dosages are required due to higher hardness levels.[10,32]

GARRISON DIVERSION

The U.S. Water and Power Resources Service (formerly U.S. Bureau of Reclamation) Garrison Diversion Project is a multipurpose water resources project designed to divert Missouri River water into central and eastern North Dakota. The water would be used to irrigate agricultural land, provide municipal and industrial water supplies, furnish recreational opportunities, and develop fish and wildlife management programs. The project was originally authorized as part of the multipurpose program included in the Flood Control Act of 1944 and was reauthorized in 1965 by Public Law 89-108.[33]

Figure 13 shows the components of the total Garrison Diversion Project as authorized in 1965. The total project includes the

Snake Creek Pumping Plant that would lift Missouri River water from Lake Sakakawea behind Garrison Dam into Lake Audubon, an impoundment adjacent to Lake Sakakawea. From Lake Audubon, the water would flow by gravity through the 73.6-mile McClusky Canal into Lonetree Reservoir. Enroute to Lonetree Reservoir, the McClusky Canal water would pass through a large screening structure designed to prevent the passage of fish and other aquatic life. Lonetree Reservoir would be created by construction of Lonetree Dam on the upper Sheyenne River, Wintering Dam on the headwaters of the Wintering River, and the James River Dikes on the headwaters of the James River. Water from the 424,000-acre-foot reservoir would be diverted by gravity into the Souris, Red and James River basins and the Devils Lake basin. The water would be diverted through a system of canals and pipelines.[33]

The Snake Creek Pumping Plant, McClusky Canal, and the Lonetree Reservoir projects are the principal supply works. The Snake Creek Pumping Plant is completed and the McClusky Canal is essentially complete. The construction of Wintering Dam and land acquisition for the Lonetree Reservoir is complete. The remaining portions of the Lonetree Reservoir include the construction of Lonetree Dam, James River Dike, and other minor dikes.[33]

The total Garrison Diversion Project encompassed the irrigation of 250,000 acres of land through the facilities and series of canals shown on figure 13.[33] The annual transfer of 510,000 acre-feet of water would also provide municipal and industrial water, fish and wildlife conservation, and recreation. However, the total plan has been challenged on the basis that the quantity and quality of return flows may adversely affect the environment and the potential uses of the receiving streams. Canada is primarily concerned that the return flows may injure health and

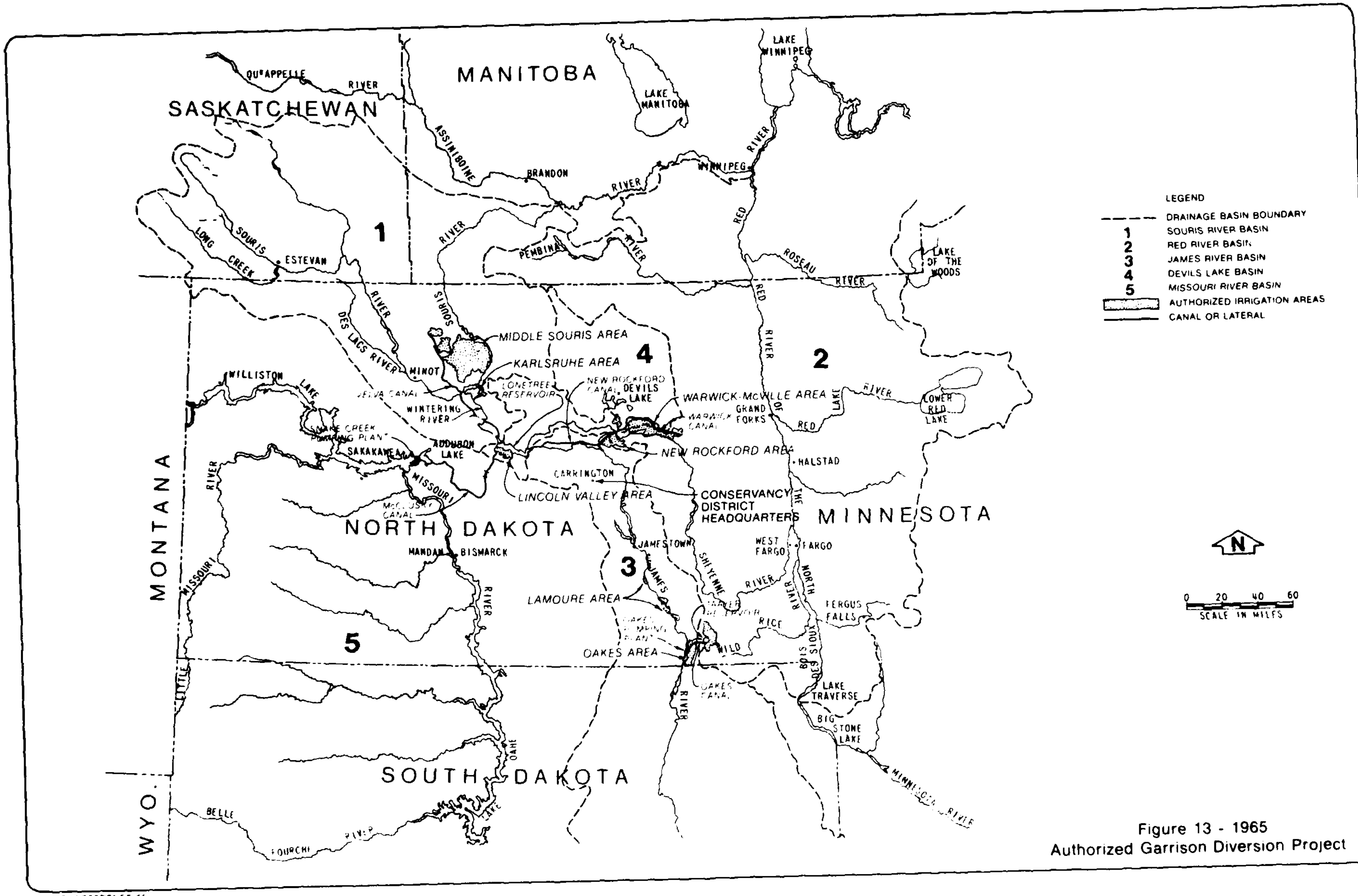


Figure 13 - 1965
Authorized Garrison Diversion Project

SOURCE REFERENCE

property in Canada and may introduce foreign biota. The concerns over the impacts of return flows are summarized as follows:[33]

1. The impact on the amount and frequency of flooding.
2. The impact on the quality of receiving streams due to increased concentrations of constituents through evaporation, transpiration, and leaching. The concerns include increases in suspended solids, increases in dissolved solids, and other changes.
3. The impact on fish and wildlife resources due to changes in water quality and quantity and potential transfer of foreign biota, particularly fish and fish parasites.

Since the conception of the Garrison Diversion Project, much international discussion, many studies, general and extensive environmental impact statements, and several court tests have been undertaken to better determine the impacts of the projects. An agreement between the National Audubon Society and the Department of the Interior resulted in a Final Comprehensive Supplementary Environmental Statement dated February 1979.[29] This study summarized and compared six alternative plans which would reduce the size of the 1965 authorized project. A modification to the 1965 authorized project would require reauthorization through legislation.

The Staté of North Dakota is currently involved in litigation regarding the size of the Garrison Diversion Project. North Dakota is continuing to work for the implementation of the full Garrison Diversion Project and the originally authorized 250,000 acres of irrigation.

Figure 14 shows the current Department of the Interior recommended Garrison Diversion Project. This plan includes 96,300 acres of irrigation, municipal water service to 15 communities, recreational development in five areas, and development of lands for fish and wildlife management. The components of this plan include the existing Snake Creek Pumping Plant, the McClusky Canal and the

portions of the Lonetree Reservoir constructed under the 1965 authorizing act. The recommended facilities to be constructed under the modified plan are the completion of the Lonetree Reservoir, the New Rockford Canal, and the James River Feeder Canal, all of which would be reduced in size.[34]

The recommended Garrison Diversion Project modification is directed at achieving the elimination of extensive supply works (canals, etc.), reducing costs, and minimizing environmental damage (including return flow water quality and quantity problems), while at the same time formulating a reasonable and economically viable plan. This plan would greatly reduce the potential for interbasin biota transfer. About 225,000 acre-feet of water would be diverted annually. However, the plan would transfer water to the Sheyenne River in the Red River of the North Basin. This water would eventually enter Canada.[34]

The Final Environmental Impact Statement on the Garrison Diversion Project indicates that the water quality of the Red River of the North will be changed very little under the recommended plan and will increase by only minor amounts under the original total plan. The mean monthly concentrations of total dissolved solids, sulfates, and hardness increase slightly but there will be no effect on the stream's water uses.[29]

The Secretary of the Interior has not finalized his recommendation and has not released the proposed legislation necessary to authorize and fund the current recommended plan. Evidently, the recommended transfer of water to the Red River of the North basin is still unacceptable. Although specific reasons for the delays have not been expressed by the Secretary of the Interior, it appears that all environmental and political constraints must be overcome before the projects can be continued. The State of North Dakota is continuing to lobby for the full Garrison Diversion Project as authorized in 1965. Therefore, the magnitude of the project that will be implemented is unknown.

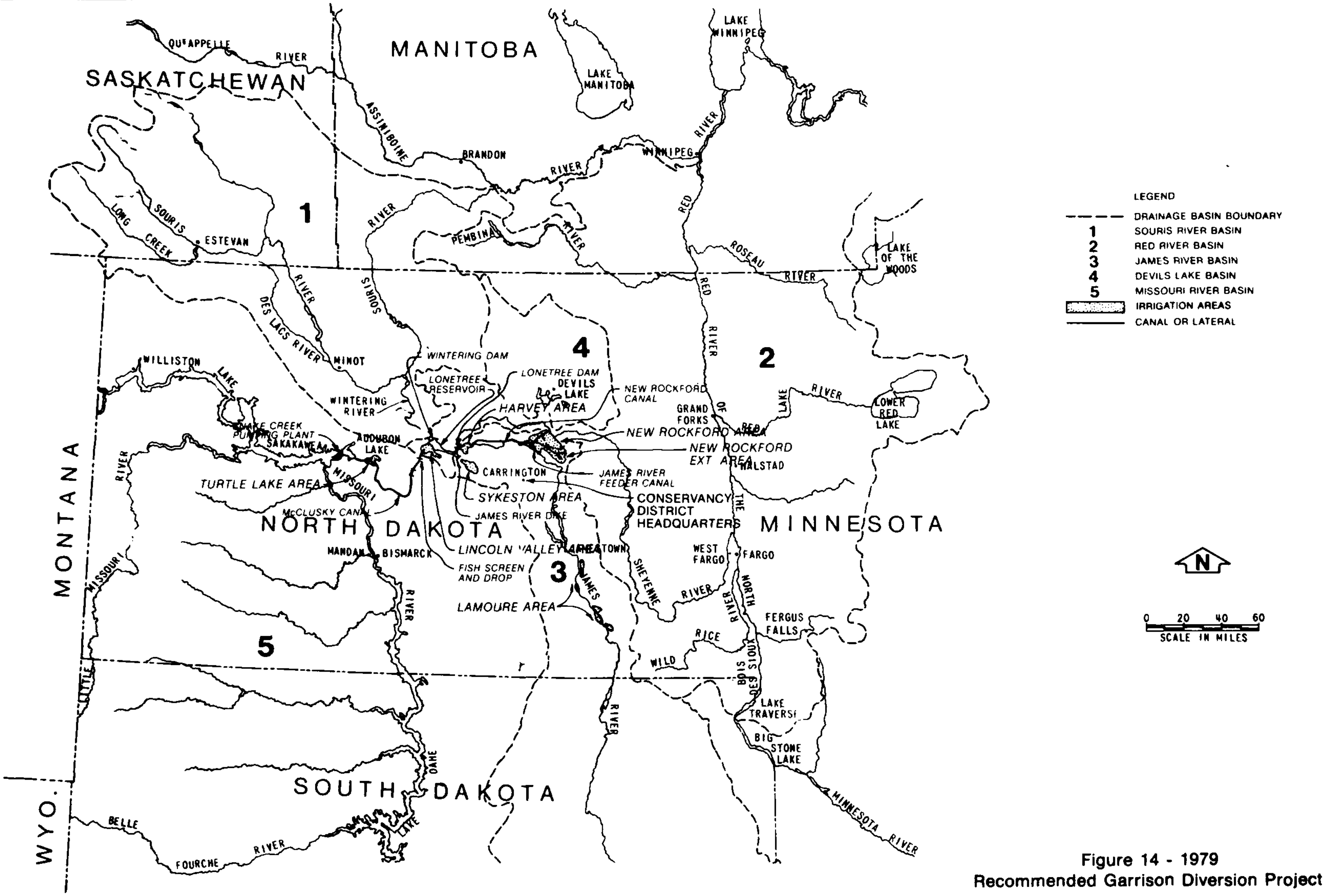


Figure 14 - 1979
Recommended Garrison Diversion Project

SOURCE REFERENCE 61

Discussions with U.S. Water and Power Resources Service personnel indicate that a reasonable approach for implementing the Garrison Diversion Project could be as follows:

1. A pilot project which diverts flow to the James River would be undertaken. Long-term monitoring of the water quality, fauna, and flora would be used to determine the environmental impacts.
2. If no significant adverse environmental impacts occur in the James River, diversion of water to the Souris River basin would be undertaken along with long-term monitoring.
3. Then, if environmental objections are overcome, water would be diverted to the Red River of the North basin.

Long-term monitoring would be required for a sufficient period to establish trends. Therefore, it would be a number of years before water would be diverted to the Red River of the North.[35] An alternative to transfer water only to the James River basin which returns to the Missouri River was not considered in the Final Supplementary Environmental Statement.[35]

The above analysis indicates that the Garrison Diversion Project cannot be counted on to satisfy urban area water demands. If the environmental and political constraints can be overcome, the project may be reactivated and completed. However, based upon discussions with U.S. Water and Power Resources Service personnel, this is unlikely in the near future.

Physically it would be possible to discharge water directly from McClusky Canal to the Sheyenne River if some channel improvements are made. However, under the planned project, the remainder of Lonetree Reservoir, a sand filter located at Lonetree Dam and removal of a plug in the McClusky Canal would have to be complete. Water for municipal and industrial uses in the Red River of the North basin will be discharged directly from Lonetree Dam, through the sand filter, and into the upper reaches of the Sheyenne River.

The current estimated cost which Grand Forks and East Grand Forks would be charged is \$50-\$55 per acre-foot in 1976 dollars or \$62-\$68 per acre-foot in January 1979 dollars for water specifically released for them. This cost does not include intake structures, transmission pipelines, storage reservoirs, or treatment plants. If the cities use irrigation return flows, there would be no charge to the cities.[36]

The released water would travel a considerable distance in the Sheyenne River and Red River of the North before reaching the GF/EGF urban area. The water would pass through Lake Ashtabula and proposed Kindred Lake, both on the Sheyenne River. Coordination with the Corps of Engineers would be required for releasing flow from these lakes. Water losses through evapotranspiration and seepage would be great. The water would also pass many farms, industries, and other communities. The institutional details for ensuring that each user receives water released for him have not been worked out. Grand Forks and East Grand Forks would probably be receiving a combination of irrigation return flows, natural streamflows, and water released for their specific needs. East Grand Forks would also have to build a Red River of the North intake.

Before Grand Forks and East Grand Forks could obtain water directly from the Garrison Diversion Project, each city would have to pass a resolution stating its needs. A formal request must then be sent to the Garrison Diversion Conservancy District at Carrington, North Dakota. Neither city has made a formal request. This procedure would ensure water is allocated to these cities.

GROUNDWATER SOURCES

Groundwater can be obtained in the urban area from bedrock and overlying glacial drift deposits. However, most of the sources are not satisfactory as urban area water supply sources because of water quality, water quantity, and aquifer yield

limits. The primary limiting factor for the glacial drift aquifers is the amount of recharge.

Figure 15 locates the major glacial drift aquifers which are near the GF/EGF urban area. Table 9 summarizes the physical characteristics of these aquifers. Table 10 lists the representative chemical characteristics of the water obtained from these aquifers. In general, only the Elk Valley, Inkster, and Beach Ridge aquifers contain relatively good quality water. The Elk Valley and Beach Ridge aquifers will be discussed in more detail below. The Inkster aquifer will not be considered further because it has a relatively small storage volume and recharge area. Also, the Inkster aquifer is currently used by a rural water district and local farmers. The other aquifers are not considered further because they contain very saline water, have relatively small storage volumes, or exhibit low well yields.

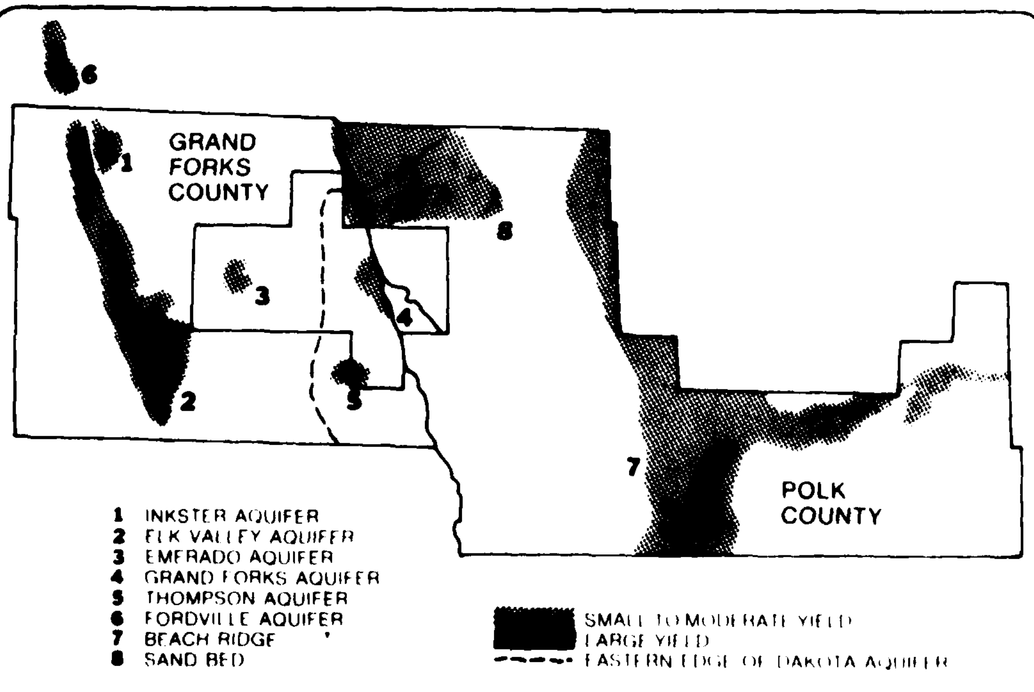


Figure 15 - Major Glacial Drift Aquifers, Grand Forks and Polk Counties

Table 9 - Physical characteristics of aquifers

Name	Area (sq mi)	Depth Interval (ft)	Average Thickness (ft)	Estimated Storage (ac-ft)	Potential Yield (gpm)
Inkster	11	5-70	27	60,000	50-500
Elk Valley	200	5-75	34	1,300,000	50-500
Emerado	15	80-110	15	43,000	50-500
Grand Forks	20	175-215	18	69,000	50-250
Thompson	8	121-150	25	38,000	50-250
Fordville	28	5-55	20	100,000	50-500
Beach Ridge	180	10-30	10	175,000	10-20
Sand Bed	290	160-175	10	500,000	5-50

Source: References 39 and 40

The bedrock aquifers under the area are generally characterized by low well yields, small storage volumes, and highly mineralized water.[40,41] The Dakota bedrock aquifer can produce higher yields (up to 500 gpm) but the water is primarily used for livestock watering due to its poor quality.[40] The Dakota aquifer outcrops and results in artesian flows along a line located at approximately the eastern one-third of Grand Forks County.[40]

Regionally, the groundwater movement is toward the Red River of the North. Geochemical data indicate a progressive water quality change as the water flows through Grand Forks and Polk Counties changing from a low-salinity calcium bicarbonate type to a high-salinity sodium sulfate chloride type.[40,41]

The GF/EGF urban area is located in a semiarid region of the United States where the mean annual precipitation is about 20 inches per year. Only about 2 inches per year of this precipitation will recharge the glacial drift aquifers and be available as a source of water supply.[37,38] The year 2030 publicly supplied average day water demands were previously projected to be 16.53 mgd (11,500 gpm or 18,517 ac-ft per year).

Table 10 - Representative chemical characteristics of aquifers

Aquifer	User	Depth (ft.)	Concentrations (mg/l) Iron	Calcium	Magnesium	Sodium	Chloride	Potassium	Sulfate	Hardness	Total Dissolved Solids
Inkster	Observation Well	74	0.24	79	21	6.5	2	2.8	71	350	306
Elk Valley	Test Hole Near Larimore	58	0.14	90	23	16	16	4.0	63	368	426
Elk Valley	Test Hole at HWY 2 & 18	60	0.12	90	31	19	11	--	86	418	391
Emerado	Test Hole in Emerado	90	0.22	205	79	289	368	17	733	1,454	1,890
Grand Forks	Test Hole in Grand Forks	31	4.4	378	213	95	101	8.4	1,530	3,310	2,740
Grand Forks	Pillsbury Co.	294	1.6	1,623	764	823	5,644	--	627	2,387	13,938
Thompson	Test Hole in Thompson	146	1.9	270	111	1,200	1,860	27	970	2,051	4,500
Fordville	Probably similar to Elk Valley quality.										
Beach Ridge	Unknown, Reported dissolved *solids less than* 500 mg/l.										
Sand Bed	Unknown, Reported saline high total dissolved solids, probably similar to Grand Forks aquifer.										

Source: Reference 40

Therefore, approximately 175 square miles of recharge area would be required to satisfy the projected demands of all if the recharge could be used for the urban area's water supply.

Elk Valley Aquifer

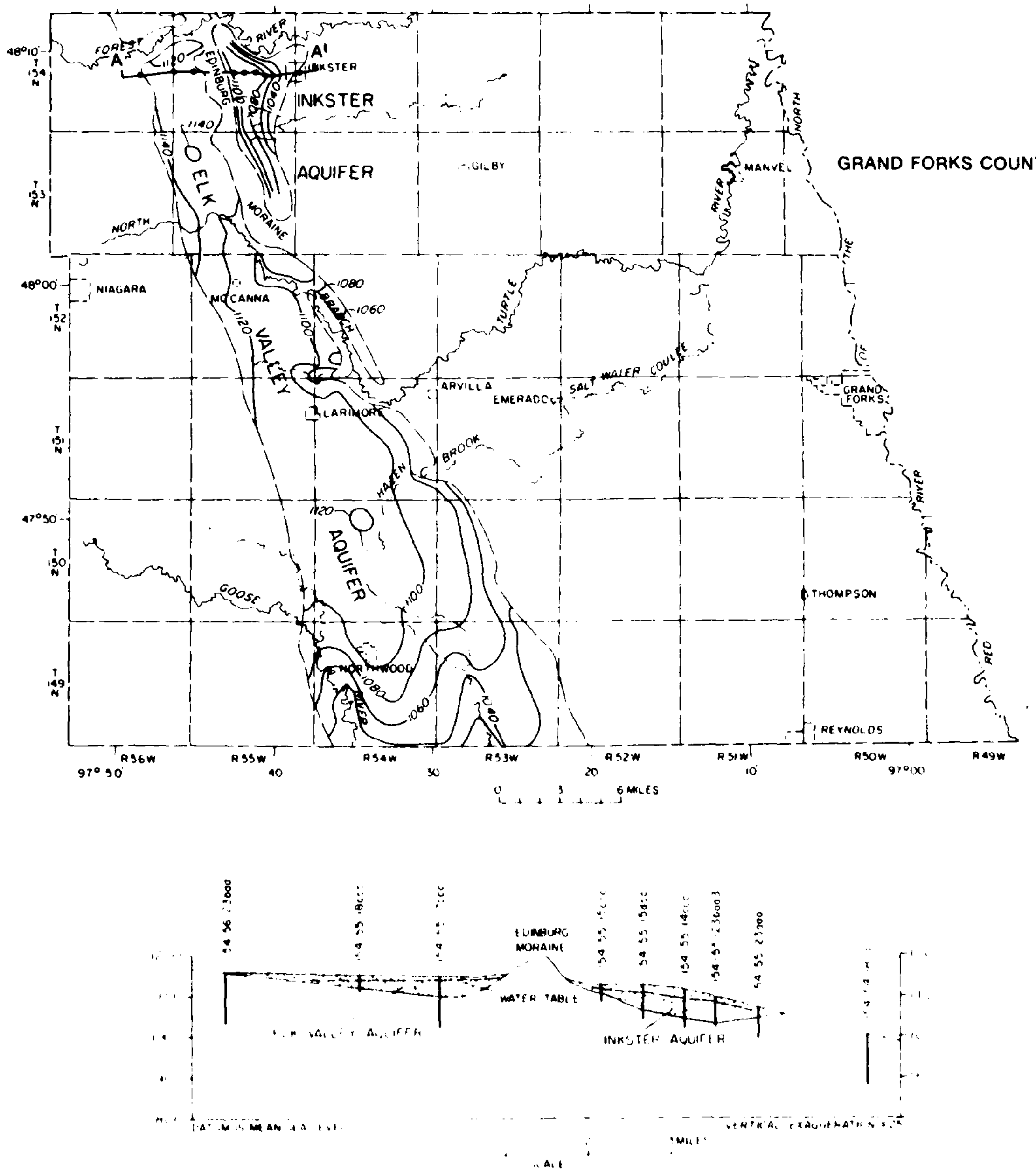
Figure 16 shows the extent and configuration of the Elk Valley aquifer. The aquifer is located along the western edge of Grand Forks County. The aquifer is composed of delta deposits that accumulated along the west bank of prehistoric Lake Agassiz and has an aerial extent of at least 200 square miles.[40]

The Elk Valley aquifer is characterized by sandy, permeable soils that readily absorb rainfall and snow melt. Consequently, there is little surface run-off and large tracts of land over the aquifer are not dissected by streams. Large quantities of ground-water are discharged from the aquifer by evapotranspiration and through springs in the stream valleys. The major spring discharges are in the valleys of the Forest and Turtle Rivers where the streams transect the aquifer.[40]

The aquifer has an average thickness of approximately 34 feet and a maximum recorded thickness of 62 feet near McCanna. The aquifer is unconfined and generally the water table is about 10 feet below the land surface. An estimated 1.0 to 1.3 million acre-feet of water are stored in the Elk Valley aquifer. The delta deposits have a general gradation from coarse materials in the north to finer materials in the south.[40]

Table 11 summarizes the results of aquifer pumping tests. The largest well yields are obtained from the fine to medium sand and gravel deposits in the north (up to 500-700 gpm). The yields become progressively smaller toward the south as the deposits become finer and contain more clay and silts (down to 10 gpm).

The pumping test on well 153-55-34ccc5 near McCanna indicates that the characteristics of the Elk Valley aquifer near this well are as follows:[40]



SECTION A-A'

LEGEND

——1100—— WATER TABLE CONTOUR Shows altitude of water table. Contour interval 20 feet. Datum is mean sea level.

— — — — — AQUIFER BOUNDARY

154-56-23 baa WELL IDENTIFICATION NUMBER

Figure 16 - Elk Valley Aquifer

SOURCE: REFERENCE 40

Table 11 - Well pumping tests, Elk Valley aquifer

Test Location	Date	Well Depth (ft)	Aquifer Interval (ft)	Screened Interval (ft)	Pumping Rate (gpm)	Duration (minutes)	24-Hour Specific Capacity (gpm per ft. of drawdown)
McCanna area 153-55-34ccc5	June 1967	62	19-62	52-62	250	6,000	11.7
City of Larimore 151-54-7ccc2	Oct. 1964	60	19-60	43-60	205 250	1,200 240	8.0
City of Larimore 151-55-12ddd1	May 1964	58	25-58	53-58	100	1,440	6.0
City of Northwood 149-54-9dac1	June 1962	52	11-52	32-52	78	1,440	6.2

Source: Reference 40

1. Transmissivity = 64,000 gpd per foot.

2. Storage coefficient = 0.19.

3. Conductivity = 1,488 gpd per sq ft = 199 ft per day.

These characteristics are representative of the fine to medium sands. The finer sands, clays, and silts have lower values for transmissivity, storage coefficient, and conductivity.

Table 12 lists the chemical characteristics of water samples obtained from the Elk Valley aquifer. These data indicate that relatively good quality water can be obtained. The total dissolved solids ranged from 337 to 1,300 mg/l (milligrams per liter) and average 630 mg/l. More than half of the samples contain less than 500 mg/l dissolved solids. Although the aquifer water is hard, it is relatively soft when compared to water obtained from other aquifers in Grand Forks and Polk Counties. As compared to the National Interim Primary Drinking Water Standards,[51] the sulfate concentration in four samples exceeded the standard of 250 mg/l as sulfate. Also, the nitrate concentration in three samples exceeded the standard of 45 mg/l as nitrate.[40]

The Elk Valley aquifer is the best groundwater source near the GF/EGF urban area. However, there are major constraints which limit its use. Based upon an annual recharge rate of 2 inches per year, approximately 175 square miles or 87.5 percent of the aquifer area would be required to satisfy the projected year 2030 average day water demand of 16.53 mgd (11,600 gpm or 18,517 ac-ft per year). The aquifer characteristics analysis indicates that wells would be spaced on 10,000-foot centers to withdraw the available water. Construction costs, rights-of-way, easements, and institutional arrangements would be major constraints.

The cities of Larimore and Northwood use the Elk Valley aquifer as their sole source of supply. The city of Ardoch, North Dakota, located on the Forest River, uses the aquifer discharge as a

Table 12 - Chemical characteristics, Elk Valley aquifer

Location	Depth	Date of Collection	Temperature (°F)	Silica (SiO_2)	Total Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved Solids: Sum	Dissolved Solids: Residue as Evaporation at 180°C	Hardness as $CaCO_3$: Calcium, Magnesium	Hardness as $CaCO_3$: Noncarbonate	Percent Sodium	Sodium-Adsorption-Ratio	Specific Conductance (micromhos at 25°C)	pH
149-53-15dcc	24	8/12/65	47	24	1.5	201	56	54	7.1	344	0	450	80	.6	.4	.30	1,050	1,090	735	453	14	.9	1,460	8.0
149-56- 4ccc	40	8/24/65	--	19	.08	152	56	——20——		360	0	332	8.0	.2	1.5	.00	766	764	610	315	7	.4	1,090	7.8
149-54- 9dac1	52	7/15/65	58	18	.10	221	[illegible]	54	9.0	410	0	525	72	.4	3.1	.20	1,180	1,250	850	515	12	.8	1,620	7.7
149-54- 9dac2	53	7/15/65	--	18	10	70	18	244	11	426	0	248	152	.2	.9	1.3	980	930	264	0	66	6.5	1,520	7.8
150-52-18ccc	12	9/ 9/66	56	29	.35	98	26	28	5.4	407	0	33	6	.2	37	.12	463	450	350	17	15	.6	727	7.9
150-53- 7daa	8.8	9/ 1/66	57	25	.38	147	40	9.3	9.4	384	0	165	6.3	.4	78	.04	649	693	530	216	4	.2	981	7.7
150-54- 7cdd1	40	7/15/65	--	16	.08	122	29	3.7	5.0	346	0	129	10	.2	.4	.10	485	537	423	140	2	.1	757	7.8
150-54- 7cdd2	27	7/15/65	57	16	.10	232	62	69	5.9	430	0	485	89	.7	11	.08	1,180	1,250	835	483	15	1.0	1,660	7.7
150-54-30aaa	15.6	7/15/65	48	15	.04	209	113	17	2.0	358	0	690	9.0	1.4	.7	.00	1,230	1,300	985	692	4	.3	1,570	7.8
151-54- 7ccc1	60	7/15/65	58	17	.04	91	20	9.5	4.3	299	0	68	11	.4	1.6	.08	370	367	308	63	6	.2	618	7.7
151-54- 7ccc2	60	7/15/65	58	18	.04	91	16	21	4.9	336	0	63	1.6	.2	.2	.30	382	425	294	19	13	.5	612	7.7
151-54-23cbb	12.9	8/12/65	50	17	.16	78	24	17	2.2	245	0	54	9.1	.3	74	.20	397	378	293	92	11	.4	628	7.7
151-54-24bbb	30	9/21/65	72	33	.01	94	31	8.1	7.8	349	0	48	3.2	.2	59	.16	456	463	360	74	5	.2	689	7.9
151-55-12ddd1	58	5/19/64	58	21	.14	90	23	16	4.0	328	0	63	16	.4	4	.00	399	426	318	50	10	.4	658	7.5
152-54-31bbb	90	9/26/65	52	20	.12	90	31	——19——		357	0	86	11	.3	1.5	.00	431	391	352	65	11	.4	696	8.0
152-54-36dac	14	7/15/65	48	14	.24	119	36	23	6.4	187	0	149	15	.3	.2	.38	554	645	446	129	10	[illegible]	886	[illegible]
152-55-14bba	18	4/22/65	50	18	.76	74	33	3.4	2	344	0	44	3.8	.5	5.8	.00	358	337	330	48	2	.1	599	7.8
153-55- 4ccd	33	[illegible]	48	18	.23	[illegible]	23	25	[illegible]	364	0	110	18	.2	0	.19	487	—	362	64	13	.6	[illegible]	8.0
153-55-32aaa	20	[illegible]	44	18	2.9	94	20	[illegible]	[illegible]	345	0	102	32	.4	.9	.08	510	—	292	0	35	1.9	866	8.0
154-55-17ccc	50	[illegible]	--	19	[illegible]	91	14	44	[illegible]	291	0	[illegible]	7.2	.1	0	.00	445	—	276	38	25	1.2	696	[illegible]
154-55-18ccc	70	[illegible]	49	17	[illegible]	[illegible]	17	24	[illegible]	240	0	110	7.2	.1	0	.39	371	—	237	41	20	.8	569	8.0
154-55-21abb	40	[illegible]	--	--	[illegible]	--	—	--	--	264	0	73	6	--	0	--	336	352	270	54	93	16	527	8.1

Source: Reference [illegible]

water supply source. Numerous farmers use the aquifer for domestic uses, livestock watering, and some irrigation purposes. The NDSWC (North Dakota State Water Commission) has expressed serious reservations over allowing the GF/EGF urban area to use the Elk Valley aquifer. More detailed studies would have to be made to determine the availability of water, existing water users, and recharge rates for the aquifer. It is unlikely that the urban area could use the entire Elk Valley aquifer at the exclusion of other users.

In conclusion, the detailed analysis of the Elk Valley aquifer reveals that the aquifer cannot be used to satisfy the urban area water demands. The primary constraint is the rate of recharge to the aquifer. The other constraints are associated with the limited rate of recharge and include well spacing and land management over the aquifer recharge area. The aquifer storage volume is also relatively small, so water cannot be mined from the aquifer.

Using the Elk Valley aquifer as a supplemental source of supply was also considered, but eliminated because of high costs. A well field system and 30 to 35 miles of transmission pipelines from the well field to the urban area would have to be constructed. The Stage 2 Water Supply Study roughly estimated that the construction cost of a well field and transmission pipeline would be about $35 million to supply all publicly-supplied urban water demands and about $20 million to supply 50 percent of the publicly-supplied urban water demands.

Beach Ridge Aquifers

The Beach Ridge aquifers are a series of long, narrow deposits of sand and gravel that mark the various stages of former glacial Lake Agassiz. These aquifers are located in Minnesota and North Dakota; however, larger deposits have been located along the east banks of the former Lake Agassiz in Minnesota. The deposits in Grand Forks County

exhibit low yields, small storage volumes, large water level fluctuations and wells that have gone dry, so these deposits will not be considered further.[40]

Figure 15 located the Beach Ridge aquifers in Polk County. The aquifers generally parallel the Red River of the North and the Red Lake River. The aquifers contain predominantly fine to coarse sand containing gravel in many places. The beach deposits vary in size and shape and range in depth up to 60 feet. Some locations contain glacial outwash and ice-contact deposits that contain medium to coarse sand and fine gravel. Smaller deposits are unreliable as a source of water supply because wells would commonly go dry in late summer and fall. The larger and deeper deposits contain larger volumes of water and yield more than 20 gpm to individual wells. The coarser outwash deposits may yield several hundred gallons per minute, and one well produced nearly 1,000 gpm.[41]

The city of Crookston, Minnesota, is planning to use a Beach Ridge aquifer as its source of supply. Crookston has obtained a water use permit from the Minnesota Department of Natural Resources. The proposed source is located about 12 miles east of Crookston. Well pumping tests indicate that 700 gpm can be obtained from the fine sand deposits. Crookston's analysis indicates that the recharge rate to the aquifer would be about 2 inches per year. The aerial extent of the aquifer could not be determined during soil boring studies and pumping tests. The city is planning to install four wells, a 20-inch diameter transmission pipeline, storage tanks, and a water treatment plant to remove iron. Although the water will be relatively hard, softening is not proposed by the city. This water system will supply Crookston's average day demands of about 1,050 gpm (1.5 mgd) and maximum day demands of about 1,750 gpm (2.5 mgd).[42]

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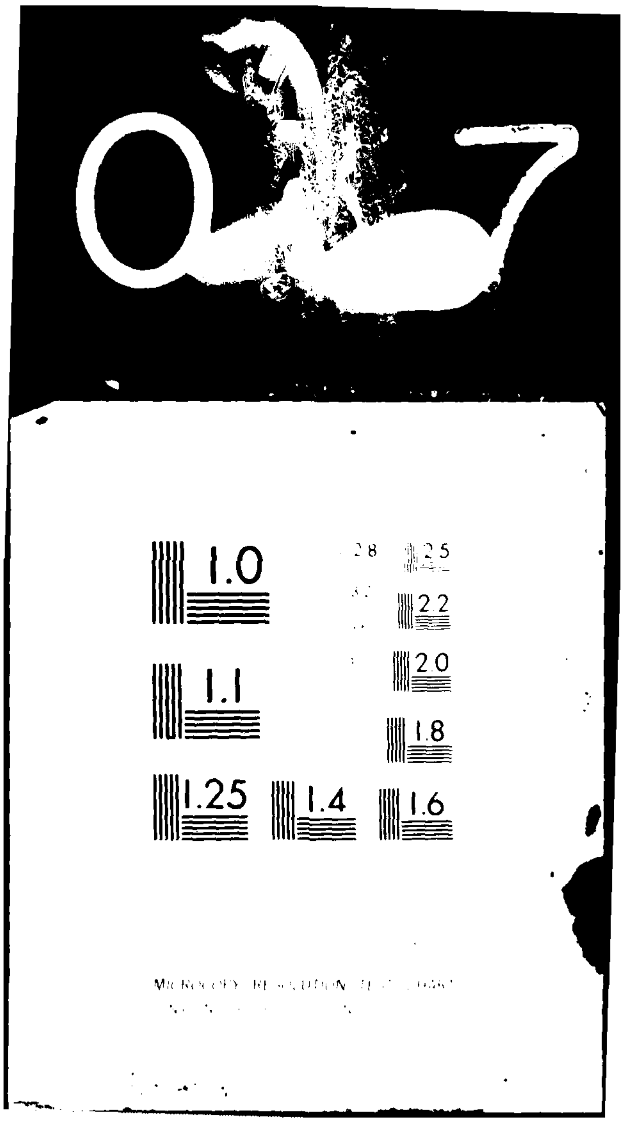
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As with the Elk Valley aquifer, the primary constraints to the use of the Beach Ridge aquifers are the recharge rate, the distance of about 40 miles from the GF/EGF urban area, and sharing of the water with other users. The Beach Ridge aquifers are not a reliable supply source for the GF/EGF urban area water demands.

The Beach Ridge aquifers as a source of supply for just East Grand Forks was investigated. The East Grand Forks average day water demand is projected to be about 2,000 gpm (2.86 mgd) in year 2030. This water demand is about 17 percent of the total urban area demand. However, the same physical, institutional, and economic constraints to using the Beach Ridge aquifer exist. East Grand Forks is located about 37 miles from the known Beach Ridge aquifers. A recharge area of 30 square miles is needed. Conflicts with existing users and land management of the recharge area are constraints. The required transmission pipeline size is smaller, but the major cost is for installation so the costs to East Grand Forks would be high. Therefore, the Beach Ridge aquifers are not a feasible water supply source for East Grand Forks.

WATER CONSERVATION MEASURES

Water conservation measures are techniques for reducing peak demands and total water use. When these measures are implemented, available water supply sources can be more efficiently used. Available water supply sources are limited in the GF/EGF area so water conservation is an important concept for extending the life of the supplies. Also, the design life of existing water storage, treatment, and distribution systems can be extended and smaller capital investments are required for expansions.

Water conservation measures may be implemented at any time. General measures are implemented during drought and nondrought conditions and are discussed below. These general measures plus

more drastic measures are implemented during drought conditions to save even more water. A "drought action plan" is discussed later in this report. Low flows are experienced in the Red River of the North and the Red Lake River nearly every year and droughts have occurred in the past. Therefore, water conservation measures should be seriously considered and implemented in the urban area.

Water conservation measures have been successfully implemented by a number of communities. Elmhurst, Illinois, cut water consumption by 10 to 15 percent during nondrought conditions and extended the design life of its water supply and treatment facilities.[43] For the same reason, the Washington Suburban Sanitary Commission achieved an approximate 4.5-percent reduction in water use under nondrought conditions.[44] The East Bay Municipal Utility District reduced water use 38 percent during drought conditions.[45]

Table 13 discusses a range of water conservation measures which can be implemented. An effective water conservation program is a multifaceted approach directed at and implemented by the general public, service organizations, industries, local governments, and water utilities. These techniques should be implemented as a comprehensive plan. Generally, five basic water conservation techniques are applicable and are as follows:

1. Reduction in treatment plant losses and distribution system leaks.
2. Public awareness and educatio.. programs.
3. Ordinances for mandating water use reduction.
4. Pricing changes to discourage water waste.
5. Industrial water conservation.

Reduction in water treatment plant losses can be achieved by recycling filter backwash and clarifier sludge drawoff water. Grand Forks has recently installed sludge handling facilities

Table 13

Methods of urban water conservation, implementation, advantages, and disadvantages

Techniques to Reduce Water Consumption	Implementation	Advantages	Disadvantages
Leak detection and repair of water agencies' distribution systems.	Institutional	1. Reduces unaccounted water losses. 2. Reduces undermining damage to streets, sidewalks, and other structures.	1. Because leaking water often percolates to usable ground water, water agencies sometimes ignore losses. 2. Low cost of lost water may not equal cost of detection and repair.
Leak detection and repair of consumers' systems.	Voluntary Institutional	1. Can reduce other home repair costs such as those from wood rot. 2. Many leaks simple and inexpensive to repair. 3. Reduces operational costs.	1. Difficult to induce flat-rate consumers and apartment dwellers to repair leaks. 2. Could be expensive to consumer if he needs professional service.
Education	Voluntary Mandatory Institutional	1. Induces voluntary water conservation. 2. Changes long established, wasteful consumer habits. 3. Achieves long-lasting results by influencing younger generation. 4. Ensures greater success and acceptance of other water saving means.	1. Effective program requires coordinated efforts of local and state agencies.
Efficient irrigation using automatic devices	Voluntary	1. Healthier plants. 2. Decreased maintenance. 3. Mechanical type savings.	1. Periodic adjustments required 2. Expensive initial cost.
Native and other low-water-using plants in landscaping.	Voluntary Institutional	1. Established native and other low-water-using plants need little or no irrigation. 2. Established plants need little care.	1. General preference for exotic plants. 2. Narrow selection of native plants in nurseries 3. Difficult to establish some low-water-using plants and general lack of knowledge on care. 4. Somewhat higher costs because native and other low-water-using plants are not readily available
Modification (retrofit) of existing plumbing fixtures.	Mandatory Voluntary Institutional	1. Many devices are nominal in cost. 2. Enables water and energy conservation in existing facilities and therefore has potential rapid, widespread savings. 3. Water savings mechanically effected. 4. Reduces wastewater conveyance and treatment load.	1. Inconsistent effectiveness of retrofit devices because of variable design and construction of existing fixtures. 2. Consumer removal or tampering with retrofit devices because of suspected poor performance 3. Some devices require skilled installation and/or follow-up adjustment. 4. May cause blockage problems in marginal sewage collection systems.
Water saving plumbing fixtures in new and replacement construction.	Mandatory	1. Mechanical devices render savings despite user habits. 2. Reduce wastewater conveyance and treatment load.	1. Possible resistance to redesign and retooling to manufacture water conserving devices. 2. Drain pipe slope tolerances are more critical 3. Initially, consumers may resist acceptance. 4. Initially, higher unit cost of water saving devices until demand increases production and reduces cost 5. May cause blockage problems in marginal sewage collection systems.
New technology.	Voluntary Institutional	1. Greater water and energy savings than conventional designed devices. 2. Reduce wastewater conveyance and treatment load.	1. Uncertain long-term effectiveness. 2. Consumer and institutional resistance to innovations. 3. Higher initial costs. 4. Conformance with existing codes and regulations, may require changes or variations. 5. May cause blockage problems in marginal sewage collection systems.
Metering	Institutional	1. Easier to implement than some of the other suggested methods. 2. May induce consumers to begin conserving water.	1. Consumer objection. 2. High capital cost. 3. Requires changes in rate structure and billing procedure.
Sewer service charges based on water consumption.	Institutional	1. More equitable than flat-rate basis to pay operational cost of sewage treatment. 2. Achieve dual benefits of reduced water consumption and wastewater flow.	1. Requires well designed rate structure. 2. Need to segregate inside and outside water consumption.
Pricing	Institutional	1. May be relatively easy to implement. 2. Can affect all customers. 3. Can be strong inducement to effect consumer savings.	1. Consumer objection. 2. Requires well designed pricing structure to achieve effective, equitable pricing. 3. Often require changes in rate structure, meter reading, and billing procedures.

Source: Reference 46

which dewater sludges and recycles the carrier water to the head end of the water plant. Therefore, water losses are minimal. East Grand Forks diverts its filter backwash and clarifier sludge waters to the sanitary sewer system. It is estimated that 15 percent of the raw water drawn from the river is lost. East Grand Forks should take steps to reduce this water loss. Steps which should be investigated include reducing filter backwash time and recycling a portion of the filter backwash water. After the initial flush of filter solids has been diverted to the sewer, the remaining backwash water could be diverted to the head end of the plant.

Reduction in distribution system losses reduces the amount of water that is unaccounted for. Unaccounted-for water is water delivered to the distribution system but not recorded by water meters for billing purposes. Both Grand Forks and East Grand Forks experience 5 to 10 percent unaccounted-for water loss which is relatively low. However, water mains will continue to deteriorate due to the area's corrosive soils. Grand Forks has an ongoing program of water main replacement that affects approximately 60 percent of its distribution system. Both Grand Forks and East Grand Forks repair leaks as they are reported or detected. A leak detection program is a useful tool for locating leaks that occur in pipe joints, valves, hydrants, and meters. Meter maintenance programs ensure water is properly recorded. Grand Forks and East Grand Forks should continue existing programs and implement additional water system maintenance programs as part of their overall system management. The primary purposes of these programs are to reduce unaccounted-for water losses and to provide an efficient level of service.

Public awareness and education programs are the most important facets of a water conservation program. They promote personal and community involvement. Educational techniques should

be designed to enlist the active and voluntary participation of the general public. The people should understand where their water comes from and that water is a limited resource. They should realize that water treatment and distribution systems are expensive to maintain and expand and that their conservation of water is an economic benefit to themselves.

Public awareness and education should be carried out through schools, the news media (T.V., radio, newspaper, etc.), water bill inserts, pamphlets, newsletters, workshops, and service organization projects. The local governments and their water utilities should promote and coordinate water conservation programs. These efforts should begin with a multimedia campaign to develop water saving habits, encourage leak repair, and promote installation of water-saving devices. The news media should be encouraged to carry public service announcements and to cover stories on changing water use patterns. A series of bill inserts, newsletters, and pamphlets should be used to explain where water is used, how it is wasted, and how to correct water losses. Speakers, workshops, and service organization projects should be sponsored to reach all age groups and cultural backgrounds so water use habits can be permanently changed. Education of young people and promotion of their participation in "wise water use" programs are the basic building blocks for long-term water conservation. Friendly competition between cities, industries, and service organizations can support water conservation programs. Other promotional activities include poster contests depicting water-saving ideas, bumper stickers, buttons, and tours of the water supply systems.

Figure 17 shows a typical distribution of residential water use. Major industrial uses would be in addition to the value shown.

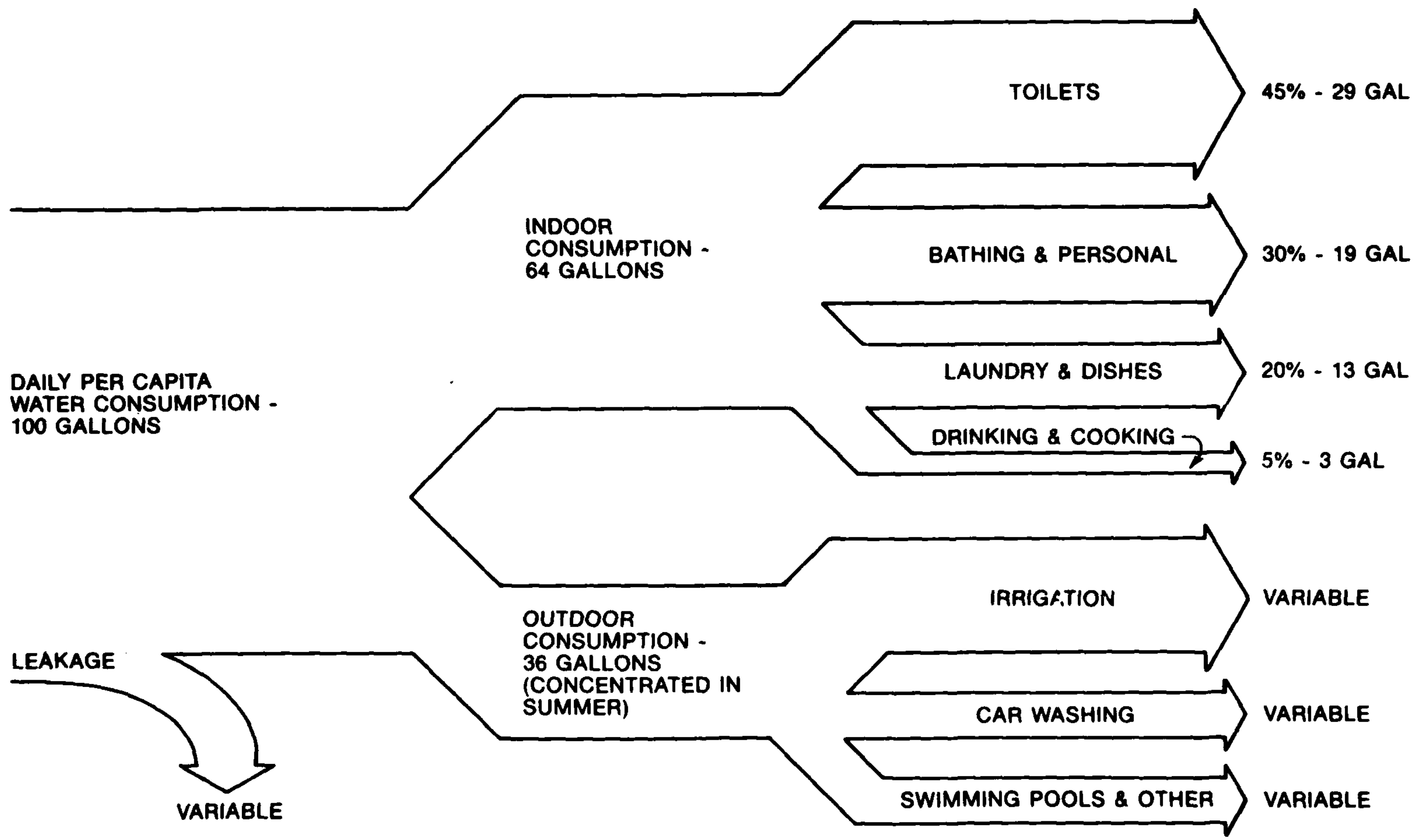


Figure 17 - Average Residential Water Consumption

Table 14 identifies sources of residential water use and potential water conservation practices for in and around the home. When residential customers understand where and how much water is used, programs directed at reducing wasteful water practices can be successful. Leakage within the home represents 5 to 10 percent of all residential water consumption.[47] Most leakage occurs due to worn out faucet washers and toilet tank valves which are easily repaired by the homeowner. A bill insert explaining the quantity of water wasted through leaks and containing leak repair instructions should be disseminated. Another bill insert, which has been successful, includes dye tablets for identifying toilet leaks. The water utility could supply faucet washers for free or at a nominal cost. The utility could provide installation and repair services to those individuals who are unable to make the repairs themselves. A telephone hotline should be available to answer questions about the water conservation program, water-saving devices, and installation.

Public awareness and education programs should promote the use of water-saving devices. These devices use less water without changing water use habits and can be installed as new plumbing fixtures or retrofitted into existing fixtures. Approximately 45 percent of the residential indoor water consumption is used for toilet flushing, and 30 percent is used for washing and bathing.[47] Toilet displacement devices (dams, bottles, or other devices) can be placed in the flush tank to reduce the volume of water required for each flush. Shower head flow restrictors (orifices) reduce the flow rate and ensure a constant flow rate even though water line pressures change. Other water-saving devices include pressure reducing valves, faucet aerators, shut-off valves on shower heads, and low water using appliances and fixtures. Residential water use can be reduced by 16 to 20 percent when toilet displacement devices and shower head flow restrictors are installed.

Table 14 - Residential water use and potential water conservation practices

Source	Typical Water Use	Potential Water Conservation Practice
Inside the Home		
Conventional Flush Toilet	5 to 7 gal/flush	Install volume displacement device or replace with water efficient type.
Conventional Shower Head	6 to 12 gal/min.	Shorten shower time or install flow restricting device.
Bath Tub	30 gal/use	Fill tub only partially full.
Faucet		Run water only when needed for washing, brushing teeth, rinsing dishes, shaving, etc.; use drain plug when practical; install faucet aerators.
Dishwasher	14 gal/load	Wash only full loads.
Clothes Washer	50 gal/load	Wash only full loads.
Garbage Disposal		Use sparingly; accumulate waste; rinse with cold water.
Outside the Home		
Lawn and Garden Watering		Water lawns sparingly; keep water from streets and sidewalks; water during off peak hours; grow native plants.
1/2-inch hose	360 gal/hr.	
5/8-inch hose	600 gal/hr.	
3/4-inch hose	1,140 gal/hr.	
Car Washing	Same as lawn watering.	Use bucket and sponge with hose for a quick rinse; ensure hose has a positive shut-off nozzle.
Cleaning Sidewalk and Driveway	Same as lawn watering.	Use broom instead of hose.
General		
All Water Faucets and Toilet Leaks		Check for and repair all leaks.
One drop/second	7 gal/day	
Steady drip	20 gal/day	
1/32-inch trickle	200 gal/day	
Excessive Water Pressure (greater than 50 psi)		Manually adjust main cutoff valve or install pressure reducing valve.

Source: Reference 48

Table 15 lists potential water-saving measures which could be used in residences. The quantity of water savings and the approximate installation cost are also presented. Retrofitting existing toilet flush tanks with displacement dams or bottles and fitting shower heads with flow restricting devices can save about 10 to 12.5 gpcd. However, with only voluntary retrofitting, only 15 to 30 percent of the homes will install these devices so the average savings would be 2 to 4 gpcd or about 5 percent of the residential indoor use. Water-saving devices installed in new construction can save up to 19 gpcd or about 30 percent of the residential indoor usage.

Ordinances for mandating water use reduction are probably the most effective means for ensuring that water conservation measures are implemented. Ordinances can be designed to reduce peak demands and/or total water use.

Table 16 describes a range of ordinances which could be adopted to achieve water savings. These ordinances can be implemented to regulate both indoor and outdoor water uses. Reducing peak demands has the most beneficial impact on water supply and treatment facilities. Peak water demands can be reduced by regulating use and when uses can occur. This type of regulation affects primarily outdoor uses such as lawn and garden watering, car washing, swimming pool filling, and water fountains. These activities can be restricted to hours when water use is normally low, such as late evening. Lawn and garden watering and car washing could be restricted to every other day or two times a week.

Ordinances to reduce the total water use and impact on the water supply source include plumbing codes that require water-saving devices in new construction and remodeling to replace existing fixtures. Typical maximum water use standards for water-saving type plumbing fixtures are as follows:

Table 15 - Potential residential interior water savings

Feature	Water Savings gpcd	Reduction in Household Water Use (%)[1]	Approximate Additional Cost[2]	Remarks
Reduced Water Toilet Devices:				
Shallow Trap Toilet	7.5	12	$13 ea.	Based on water requirement of 3.5 gal/flush.
Flush Valve Toilet	7.5	12	--	
Toilet Dam	5	8	$6 ea.	Savings higher with some toilets.
Displacement Bottles	2.5	4	20¢ ea.	Two 1-quart bottles displacing .5 gal/flush.
Flow Control Devices - Showers:				
Flow Control Head or "in line" Fitting	75	12	65¢ to $5 ea.[3]	3 gpm flow rate.
Thermostatic Mixing Valve	2	3	$24 ea.	Installed on kitchen sink & shower/bath.
Flow Control Devices - Faucets:				
Kitchen Sink	0.5	0.8	65¢ to $5 ea.[3]	Installed on kitchen sink hot & cold water, 2.5 gpm flow rate.
Lavatory	0.5	0.8	65¢ to $5 ea.[3]	Installed on bathroom lavatory hot & cold water, 2.5 gpm flow rate.
Aerators	0.5	0.8	$1 ea.	Installed on kitchen sink & lavatory faucets.
Insulation of Hot Water Pipes	2.0	3	50¢/ft.	Slit foam tubing.
Specialty Systems:				
Minuse Shower	14	22	--	
Vacuum Flush Toilet	22.5	35	--	
Compressed Air Toilet	25	39	--	

[1]Household water use taken as 64 gpcd (excludes outside irrigation).

[2]Materials only and based on 1976 cost over and above "normal" practice. Prices should be considered as "ballpark" estimates only.

[3]Price varies depending on materials. Low value is for plastic inserts. *High value is for chrome-plated brass fittings.*

Source: Reference 49

Table 16 - Water conservation ordinances program

Purpose	Discussion	Intended Results
Devices for Saving Water	• Require installation of water-saving devices in new construction.	Reduce water consumption.
	• Encourage installation of water-saving devices in existing construction.	
Waste of Water Prohibitions	• Define unreasonable uses of limited supply (especially nonessential outdoor uses such as lawn watering, car washing, filling of swimming pools, etc.)	Reduce water consumption.
	• Prohibit unreasonable uses.	Eliminate waste of limited supplies.
	• Provide for the reasonable reduction of water by public agencies.	
Rationing	• Provide sufficient supply for domestic, fire protection, and sanitation needs.	Reduce water consumption.
	• Equitably distribute remaining water supply among users by priority classifications.	Equitably distribute limited water supply.
	• Administer distribution of remaining water supply through rate surcharges, penalties, and reduction of deliveries.	
Equitable Water Rates	• Define & allocate costs of service.	Make consumers aware of consumption and cost relationship.
Expansion Limitation of Water Use	• Restrict new water service connections.	Limit increases of water consumption.
	• Limit new construction on underdeveloped properties.	Continue current ability to ration water use of existing consumers.
	• Control changes in type of water use.	
Connection Prohibitions	• Discontinue accepting new water service connection applications.	Limit increases in water consumption.

Source: Reference 50

Plumbing Fixture	Maximum Water Standards
Water Closet Tank Type	3.5 gallons per flush
Water Closet Flush-O-Meter	3 gallons per flush
Urinal Tank Type	3 gallons per flush
Urinal Flush-O-Meter	3 gallons per flush
Shower Heads	4.0 gallons per minute maximum flow
Lavatory Sink Faucets	4.0 gallons per minute maximum flow with both hot and cold water supply fully open

Ordinances requiring installation of water-saving fixtures in existing homes would be unpopular and difficult to enforce. However, retrofitting flush tank toilets with displacement devices and installing shower head flow restrictors are relatively easy and inexpensive. The local governments could purchase and deliver kits containing a set of displacement dams, shower head flow restrictors, and an instruction booklet. Under some circumstances, the water utility could install these devices. Other ordinances could be adopted as water shortages become more severe. These include rationing, higher water rates, and restricting or prohibiting new water service connections.

Pricing changes to discourage water waste are effective means for implementing water conservation measures. Both Grand Forks and East Grand Forks have declining block rate structures where the unit price of production decreases as the total production and use increase. Although the declining block rate is widely used, this structure does not encourage water conservation.

Table 17 summarizes a range of pricing systems which could be used. A lesser declining block rate, a uniform rate, a peak load rate, or an increasing block rate would reduce total water use. These rates affect the larger users most. Peak load rates affect seasonal uses such as lawn watering. Major changes to existing rates must be analyzed carefully to ensure adequate

Table 17 - Summary of pricing systems

Type of System	Definition and Comments	Degree of Equity	Discouragement of Waste
Metering	1. Not generally thought of as a pricing method, it is essential to effect most pricing programs. 2. Installation of meters in nonmetered areas usually results in decrease in consumption of at least 25%. 3. Water service for Grand Forks and East Grand Forks is metered.	Required for Equity	Yes
Flat Rate	1. Usually found in unmetered areas; each customer is charged the same regardless of the amount of water used. 2. Sometimes the rate is varied according to the size of delivery line. 3. Easy for utilities to manage. 4. Should not be considered as a proposed rate structure.	Not Equitable	No
Declining Block Rate	1. Customer is charged a certain amount for an initial quantity or "block" of water. The rate for succeeding blocks decreases with each block. 2. Type of system used by Grand Forks and East Grand Forks.	Not Equitable	No
Uniform Rate	1. Each unit of water costs the same.	Equitable	Minor
Increasing Block Rate	1. Customer is charged a certain amount for an initial quantity or "block" of water. The rate for succeeding blocks increases with each block.	Equitable	Yes
Peak Load, Excess Facilities, or Seasonal Rates	1. Customer is charged a uniform rate for a certain quantity of water. This quantity is usually based on the reduced lawn irrigation season use or on the average demands on the water distribution system. 2. Quantities used above the amounts determined in (1) are charged at a higher rate.	Equitable	Yes
Lifeline Rate	1. Establishes a low fixed rate for a minimum basic amount of water. 2. Especially appealing to older people on small fixed incomes who normally use little water, but is applicable to any low water user.	Equitable	Yes

Source: Reference 46

revenues are produced, the rates are equitable, and there is an incentive for water conservation. A new rate structure should be aimed at water waste and not penalize essential uses.

Industrial water conservation can produce the single largest reduction in total water use. For example, American Crystal Sugar has indicated that it plans to double its production without increasing water use at its East Grand Forks plant. This expansion will include modern water-saving equipment and recycling.

Table 18 lists industrial water conservation measures which could be implemented. Some measures involve capital and labor expenditures. Each industrial plant should inventory the location, purpose, and quantity of water uses. Substantial water savings can be achieved by simply eliminating unnecessary and wasteful practices. The initial program should include shutting off unused discharges, putting automatic shutoff nozzles on hoses, and using only as much water as needed. Proper management of water uses also includes recycling and reuse such as using a counterflow wash water pattern, rotating mechanical peelers, high pressure-low volume sprayers, and cooling towers rather than once-through cooling.

Each industry and industrial plant has different potentials for implementing water conservation measures. The total water use that can be expected depends upon the type of process, the condition of equipment, the education of the labor force, the commitment of management, and the current implementation of water conservation measures. Therefore, predicting the total water use savings which can be obtained through an industrial water conservation program is difficult. Past water use may not reflect actual needs because of wasteful practices.

The projected year 2030 industrial average day water use for the GF/ECF urban area is 5.62 mgd which is about 30 percent of the

Table 18 - Industrial water conservation

Summary By Processes	Significant Requirement of Capital	Labor
General, All Industries		
Reduce use of water for testing fire systems	--	--
Leak detection and correction	--	x
Turn off water when not in use	--	--
Mechanical or high pressure - low volume plant and equipment cleaning	x	--
Monitor departments or process individually with meters	--	--
Stop vehicle washing	--	--
Wastewater reuse	x	--
Reduce landscape watering	--	--
Cooling		
Machine, bearing, etc., cooling, replace single pass systems with cooling tower and recirculation systems	x	--
Reduce cooling tower bleed or blowdown to amount actually needed	--	--
Treat water electrostatically, or filter, to recirculate longer, i.e., reduce blowdown	x	--
Use wastewater where possible	x	--
Heating		
Install steam (or hot water) return lines	x	--
Use boiler blowdown for other purposes, e.g. washing	x	--
Automatic blowdown control equipment to limit amount of blowdown	x	--
Shut-down hot solution tanks when not in use to reduce evaporation	--	--
Washing		
Counterflow wash systems, i.e. reuse water for progressive less critical purposes	x	--
Recycle rinse water for washing	x	--
Reduce pavement washing	--	--
Dry clean work areas before clean up with water	--	--
Miscellaneous		
Mechanical instead of hydraulic peelers	x	--
More efficient reverse osmosis permeators	--	--

Source: Reference 51

total urban area water use. Most of the industrial water use occurs between September and May following the fall harvest. It is estimated that industrial water conservation measures can save 10 to 20 percent of the industrial water use or about 3 to 6 percent of the total urban area water use.

In summary, the GF/EGF urban area experiences droughts and water shortages regularly. Nearly every summer, low flows are experienced in the Red River of the North and the Red Lake River. Therefore, an ongoing water conservation program is needed. However, to be successful, the program must be a multifaceted program directed at and implemented by the general public, service organizations, industries, local governments, and water utilities. A viable water conservation program for the GF/EGF urban area should include the following:

1. Continuation of existing leak detection and repair programs. A comprehensive leak detection program should be undertaken by each city. A meter maintenance program is essential.
2. Initiation of a multimedia campaign to increase public awareness and education and to promote personal and community involvement. Schools and service organizations should be actively involved.
3. Water-saving devices and leak repair kits should be distributed to all customers. The kits should be free and distributed through a short-term, intensive campaign. Toilet displacement dams and shower head flow restrictors should be promoted strongly since these devices reduce water use without changing water use habits.
4. Ordinances requiring water-saving fixtures and appliances in new construction should be implemented. Lawn and garden watering should be

allowed only between the off-peak hours from 10 p.m. to 6 a.m.

5. Industrial water conservation measures such as shutting off unused discharges and providing automatic shutoff nozzles should be promoted.

6. A pricing system which discourages water waste while allowing essential uses should be implemented. The pricing system should use an excess or peak-use charge.

7. East Grand Forks should reduce its filter backwash water waste as much as possible by minimizing filter backwash time and recycling some of the backwash water.

Table 19 summarizes the projected urban water demands which the above water conservation program could achieve. The impact of water conservation is shown by comparing table 19 values with water demands presented in tables 6 and 7. Implementation of a multifaceted, comprehensive water conservation program in the GF-EGF urban area could reduce the total water use by approximately 8 percent during nondrought conditions. This program would reduce the maximum day demands by about 10 percent. These reductions can be expressed in other ways:

1. The year 2030 total water use would be reduced by about 1.3 mgd or approximately 13,000 more people could be served without increasing year 2030 water demand projects.

2. The year 2030 water treatment plant capacity needed would be reduced by about 10 percent or 3.0 mgd.

3. The existing Grand Forks water plant, which should be immediately expanded, could satisfy demands through 1980 or 1981.

4. The existing East Grand Forks plant could satisfy demands through year 2015 or for another 10 years.

Table 19 - Projected urban water demands with water conservation

	Water Demands (mgd)					
	1980	1990	2000	2010	2020	2030
Annual Average Day:[1]						
Grand Forks	7.09	7.90	8.87	9.96	11.20	12.58
East Grand Forks	1.38	1.57	1.79	2.04	2.32	2.63
Total Public Supply from Surface Water	8.47	9.47	10.66	12.00	13.52	15.21
Self-Supplied Industries Using Surface Water	0.58	0.58	0.58	0.58	0.58	0.58
Total Surface Water Demand	9.05	10.05	11.24	12.58	14.10	15.79
(cfs)	(14.00)	(15.55)	(17.39)	(19.46)	(21.80)	(24.42)
Self-Supplied Industries Using Groundwater	0.14	0.14	0.14	0.14	0.14	0.14
Total Urban Demand	9.19	10.19	11.3[illegible]	12.72	14.24	15.93
Maximum Day:[2]						
Grand Forks	11.93	13.29	14.92	16.77	18.84	21.16
East Grand Forks	2.51	2.86	3.27	3.72	4.22	4.79
Total Public Supply from Surface Water	14.44	16.15	18.19	20.49	23.06	25.95
Self-Supplied Industries Using Surface Water	--	--	--	--	--	--
Total Surface Water Demand	14.44	16.15	18.19	20.49	23.06	25.95
(cfs)	(22.25)	(24.98)	(28.14)	(31.70)	(35.67)	(40.14)
Self-Supplied Industries Using Groundwater	--	--	--	--	--	--
Total Urban Demand	14.44	16.15	18.19	20.49	23.06	25.95

[1] Water conservation is projected to reduce the average day demands (total water use) by 8 percent.

[2] Water conservation is projected to reduce the maximum day demands by 10 percent.

Source: Stanley Consultants

ADEQUACY OF WATER SUPPLY SOURCES

The analyses of the alternative water supply sources are summarized as follows:

1. The Red River of the North and Red Lake River can satisfy urban area water demands except for short periods during extreme drought conditions similar to those experienced in the 1930's. Supplemental storage is required for about 29 days during a 50-year drought and the storage volume needed is about 126 ac-ft. In-channel storage is estimated to be 3,200 ac-ft so no off-channel storage is required. The existing low-head dams must be properly maintained and replaced as necessary.
2. The Elk Valley aquifer cannot satisfy the GF/EGF urban area water demands because the recharge rate to this aquifer is limited to approximately 2 inches per year. About 175 square miles of the aquifer area would be required to satisfy year 2030 water demands. The construction costs, recharge area land management, rights-of-way, and institutional arrangements are other major constraints.
3. The Beach Ridge aquifers cannot satisfy the GF/EGF urban area water demands because the recharge rate is limited to approximately 2 inches per year. These aquifers cannot satisfy East Grand Forks demands separately due to the recharge rate, high costs, and other constraints as identified for the Elk Valley aquifer.
4. The Garrison Diversion project has been challenged on the basis that the quantity and quality of return flows may adversely affect the environment and the potential uses of the receiving streams.

Before Garrison Diversion water could be transferred to the Red River of the North, the environmental and political concerns must be overcome. Therefore, at the present time the Garrison Diversion project cannot be counted on to satisfy GF/EGF urban area water demands.

5. Water conservation is a viable means of reducing water demand and therefore extending the useful life of water supply sources. However, the local governments must be committed to implementation of a comprehensive and extensive program. There is some local resistance to implementation of water conservation practices. Therefore, water supply and treatment facilities will be designed for normal usages. If water conservation practices are implemented, the useful life of these facilities would be extended.

WATER TREATMENT ALTERNATIVES

GENERAL

Water from each alternative water supply source discussed in the previous section must be treated before it can be used as a potable water for consumption. The degree of treatment depends on the quality of water obtained from each source. All sources require water softening, and surface water sources require pretreatment to remove suspended solids, taste, odor, and color. Depending on Environmental Protection Agency regulations, advanced water treatment may be required to remove organics.

Water treatment plants are normally designed to treat maximum day demands. A minimum of two parallel treatment trains is required to ensure reliability. Operational flexibility should be included in the plant design.

WATER QUALITY STANDARDS

All public water systems must comply with the Federal Safe Drinking Water Act (Public Law 93-523). This law, enacted on 16 December 1974, empowered the EPA (Environmental Protection Agency) to establish national drinking water quality standards. Individual States may obtain the authority from the EPA for enforcing these standards and supervising public water systems. Both North Dakota and Minnesota have accepted the authority and have enacted State laws which establish the necessary legal and administrative structure.

The EPA's water quality standards are divided into primary and secondary regulations. The primary regulations pertain to water quality constituents that affect the health of consumers. The second regulation includes those constituents that primarily affect aesthetic qualities of drinking water.

The National Interim Primary Drinking Water Regulations became effective on 24 June 1977.[52] An amendment to the primary standards became effective 29 November 1979 and was for the control of trihalomethanes in drinking water.[53] Also, following other National Academy of Sciences studies of the human health effects of exposure to contaminants in drinking water, revised National Interim Drinking Water Regulations will be promulgated.

Secondary Drinking Water Regulations were enacted by the EPA on 19 July 1979.[54] The secondary regulations are not federally enforceable and are intended as guidelines for the States.

Table 20 summarizes the National Interim Primary Drinking Water Standards. The MCL (maximum contamination levels) for 10 inorganic chemicals, 6 organic pesticides and herbicides, 2 categories of radionuclides, and turbidity are presented. The standards also established MCL's for coliform organisms depending upon the testing technique and sample size and are summaried as follows:

1. When the membrane filter technique is used, the number of coliform bacteria shall not exceed any of the following:
   a. One per 100 milliliters as the arithmetic mean of all samples examined per month;
   b. Four per 100 milliliters in more than one sample when less than 20 are examined per month; or
   c. Four per 100 milliliters in more than 5 percent of the samples when 20 or more are examined per month.
2. When the fermentation tube method and 10 milliliter standard portions are used, coliform bacteria shall not be present in any of the following:
   a. More than 60 percent of the portions in any month;
   b. Five portions in more than one sample when less than five samples are examined per month; or
   c. Five portions in more than 20 percent of the samples when five or more samples are examined per month.

Table 20 - National interim primary drinking water standards

Contaminant	Temperature[1] °F	°C	Maximum Contaminant Level
Arsenic			0.05 mg/l
Barium			1.0 mg/l
Cadmium			0.01 mg/l
Chromium			0.05 mg/l
Lead			0.05 mg/l
Mercury			0.002 mg/l
Nitrate (as N)			10.0 mg/l
Selenium			0.01 mg/l
Silver			0.05 mg/l
Fluoride	53.7 and below	12.0 and below	2.4 mg/l
	53.8 to 58.3	12.1 to 14.6	2.2 mg/l
	58.4 to 63.8	14.7 to 17.6	2.0 mg/l
	63.9 to 70.6	17.7 to 21.4	1.8 mg/l
	70.7 to 79.2	21.5 to 26.2	1.6 mg/l
	79.2 to 90.5	26.3 to 32.5	1.4 mg/l
Endrin			0.002 mg/l
Lindane			0.004 mg/l
Toxaphene			0.005 mg/l
2, 4-D			0.1 mg/l
2, 4, 5 - TP (Silvex)			0.01 mg/l
Methoxychlor			0.1 mg/l
Alpha Emitters			
Radium - 226			5 pCi/l
Radium - 228			5 pCi/l
Gross Alpha Activity (Excluding radon and uranium)			15 pCi/l
Beta and Photon Emitters[2]			
Tritium			20 pCi/l
Strontium			8 pCi/l
Turbidity			1 turbidity unit[3]

[1] Annual average of the maximum daily air temperature.

[2] Based upon a water intake of 2 liters/day. If gross beta particle activity exceeds 50 pCi/l, other nuclides should be identified and quantified on the basis of 2 liters/day intake.

[3] One turbidity unit based on a monthly average. Up to 5 turbidity units may be allowed for the monthly average if it can be demonstrated that no interference occurs with disinfection or microbiological determinations.

Source: References 52, 55, and 60

One of the major reasons for implementing the Safe Drinking Water Act was to determine the effect of certain organic chemical contaminants on human health and how best to control them. Chlorinated organic chemicals are suspected of causing cancer in humans following long-term exposure and/or exposure to high concentration. Organic chemical contaminants in drinking water are derived from two principal sources:

1. From chlorination practices at the water treatment plant (trihalomethanes and many other chemicals).
2. From direct or indirect industrial discharges, agricultural sources (pesticides), and urban and agricultural runoff.

The EPA has conducted numerous studies on the organic chemical contaminants and has enacted the first of a two-part regulation consisting of the following:[53]

1. For TTHM's (total trihalomethanes) including chloroform, an MCL of 100 micrograms per liter (100 parts ber billion).
2. For synthetic organic chemicals, a treatment technique requiring granular activated carbon or its equivalent.

The TTHM regulation applies to systems serving 10,000 or more persons that use a disinfectant in water treatment. The regulation will take effect 2 years from the effective date for systems serving 75,000 persons or more and 4 years from the effective date for systems serving 10,000 to 75,000 persons. Systems serving 75,000 or more persons are required to begin monitoring within 1 year from the effective date. Systems serving 10,000 to 75,000 persons will be required to begin monitoring the TTHM's within 3 years after the regulations become effective. Systems serving less than 10,000 persons are not required to comply with the MCL or conduct monitoring unless States exercise their discretion to expand coverage to these systems. The proposed treatment technique regulation requires water systems serving more than 75,000 persons to use granular activated carbon or its equivalent in their drinking water treatment systems. The proposed treatment regulation is still being studied.

There has been considerable discussion and study concerning the proposed organic chemical contaminant regulation. Arguments include demonstration of human health effects, costs, treatment technology, research adequacy, and TTHM regulations should apply to all systems if TTHM's are really hazardous. The organic chemical regulations will be finalized sometime in the future, but their final form can only be speculated.

Table 21 lists the National Secondary Drinking Water Regulations. These standards are goals which should be attained but are not federally enforceable. High concentrations of these constituents are not known to cause any serious health hazard. However, the aesthetics which should be considered include red water caused by iron content, bad taste and odor, laxative effects, scaling, and other problems which may discourage the use of a water source by the public.

Table 22 compares the interim Primary Drinking Water Standards and Secondary Drinking Water Standards with the standards currently used by North Dakota, Minnesota, and the Air Force Base. The State standards may be more stringent than the EPA's, but not less stringent. The EPA also encourages the States to enforce the Secondary Drinking Water Standards. Both States have indicated that they will accept the responsibility for implementing the proposed organic chemical contaminant regulations when they are finalized.

Table 21 - Secondary drinking water standards

Substance	Maximum Concentration
Chloride	250 mg/l
Color	15 Color Units
Copper	1 mg/l
Corrosivity	Noncorrosive
Foaming Agents	0.5 mg/l
Hydrogen Sulfide	0.05 mg/l
Iron	0.3 mg/l
Manganese	0.05 mg/l
Odor	3 Threshold Odor Number
pH	6.5 - 8.5
Sulfate	250 mg/l
Total Dissolved Solids (TDS)	500 mg/l
Zinc	5 mg/l

Source: Reference 53

WATER TREATMENT ALTERNATIVES

Figure 18 shows the plan view of a typical water treatment plant. This plant could satisfy all currently existing and proposed water quality standards for the water supply sources being considered. The unit processes needed for each source depends upon the raw water quality to be treated. Each source contains different contaminants, so the required plant would be established by deleting various unit processes from the typical plant. Water treatment plants for surface water, advanced surface water, and groundwater treatment are considered.

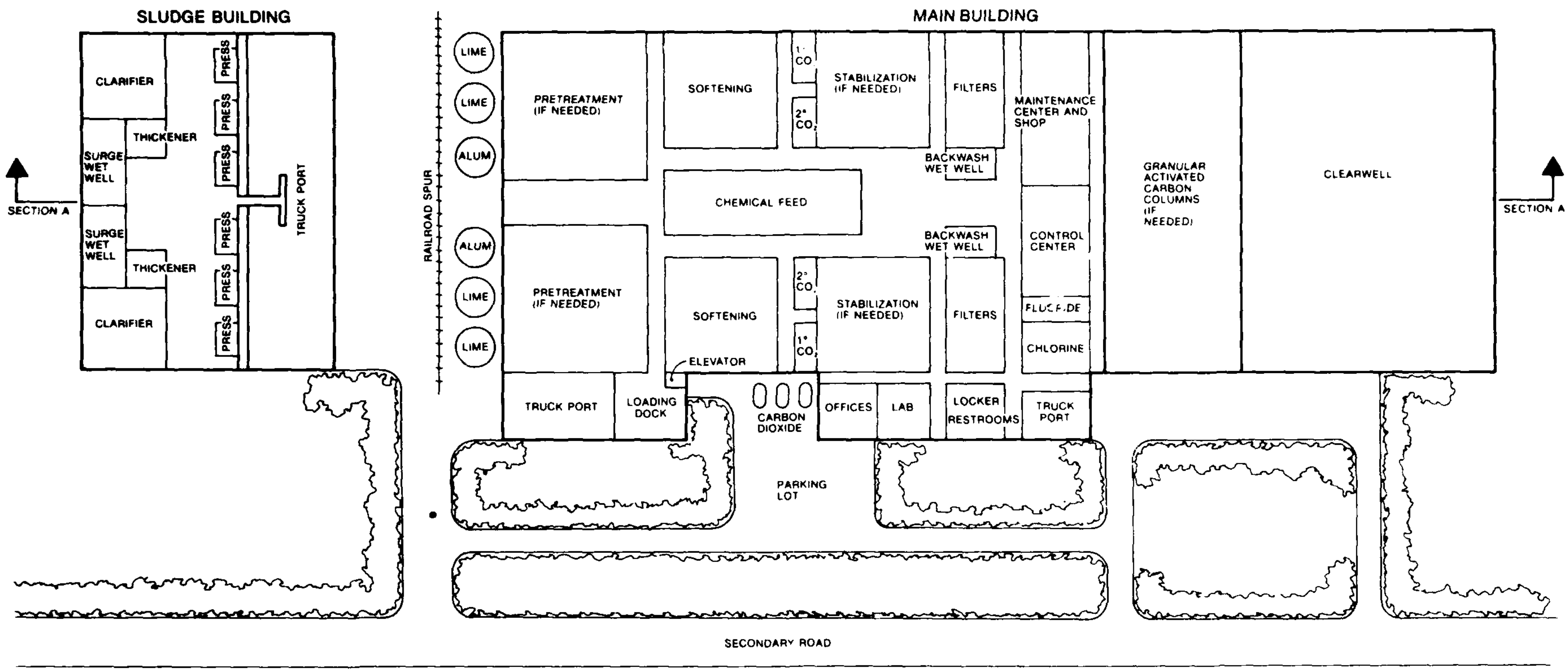


Figure 18 - Typical
Water Treatment Plant, Plan View

Table 22 - Comparison of water quality standards[1]

	Air Force Criteria In Raw Water (56)	North Dakota Water Quality Standards Red River (57)	Minnesota Water Quality Standards Red River and Red Lake River (58)	EPA Criteria in Drinking Water (52)(54)
Physical				
Color (units)	75	15	15	15
Turbidity (NTU)	--	10	25	1 (monthly average)
Total Dissolved Solids	500	500	500	500
Inorganic Chemical				
Arsenic (mg/1)	0.10	0.05	.01	0.05
Barium (mg/1)	1.0	1.0	1.0	1.0
Cadmium (mg/1)	.01	.01	.01	.01
Chromium (mg/1)	.05	.05	1.0	.05
Chloride (mg/1)	250	100	250	250
Copper (mg/1)	1.0	.05	.20	1.0
Lead (mg/1)	.05	.05	.05	.05
Manganese (mg/1)	.05	--	.05	.05
Mercury (mg/1)	.002	.002	--	.002
Nitrate Nitrogen (mg/1 as N)	10	1.0	45	10
Selenium (mg/1)	.01	.01	trace	.01
Silver (mg/1)	--	--	.05	.05
Sulfate (mg/1)	250	250	250	250
Zinc (mg/1)	5	1.0	1.0	5
Ammonia (mg/1)	0.5	.02	2.0	--
Biological				
Total Coliform	20,000/100 ml	--	--	1/100 ml (monthly average)
Fecal Coliform	2,000/100 ml	200/100 ml	250/100 ml	--

[1]Represent maximum values acceptable.

Sources: Based on References shown.

Figure 19 displays a schematic of the typical water treatment plant and shows the piping, valving, and chemical feed requirements. The piping requirements form the building blocks for arranging the unit processes. The physical arrangements considered include transporting liquid and sludges to and from unit processes, operational flexibility, and future expansion.

Figure 20 presents a section view of the typical water treatment plant. This section shows the hydraulic profile required for gravity flow through the liquid treatment processes. The first unit process required should sit on the ground surface while the remaining processes must be excavated.

Surface Water Treatment

The unit processes required for surface water treatment are similar to those used by Grand Forks and East Grand Forks. Grand Forks uses pretreatment and two-stage softening while East Grand Forks uses pretreatment and one-stage softening. The Grand Forks two-stage softening process was originally an experiment designed to treat the high magnesium hardness found in Red River of the North water. The two-stage process uses a high pH to precipitate magnesium hydroxide in the first softening stage, then adjusts the pH to precipitate calcium carbonate in the second stage. This two-stage process has worked well for Grand Forks and the city likes the feature of added flexibility. East Grand Forks treats Red Lake River water which has relatively better water quality than the Red River of the North. The one-stage softening process has adequately treated the Red Lake River water.

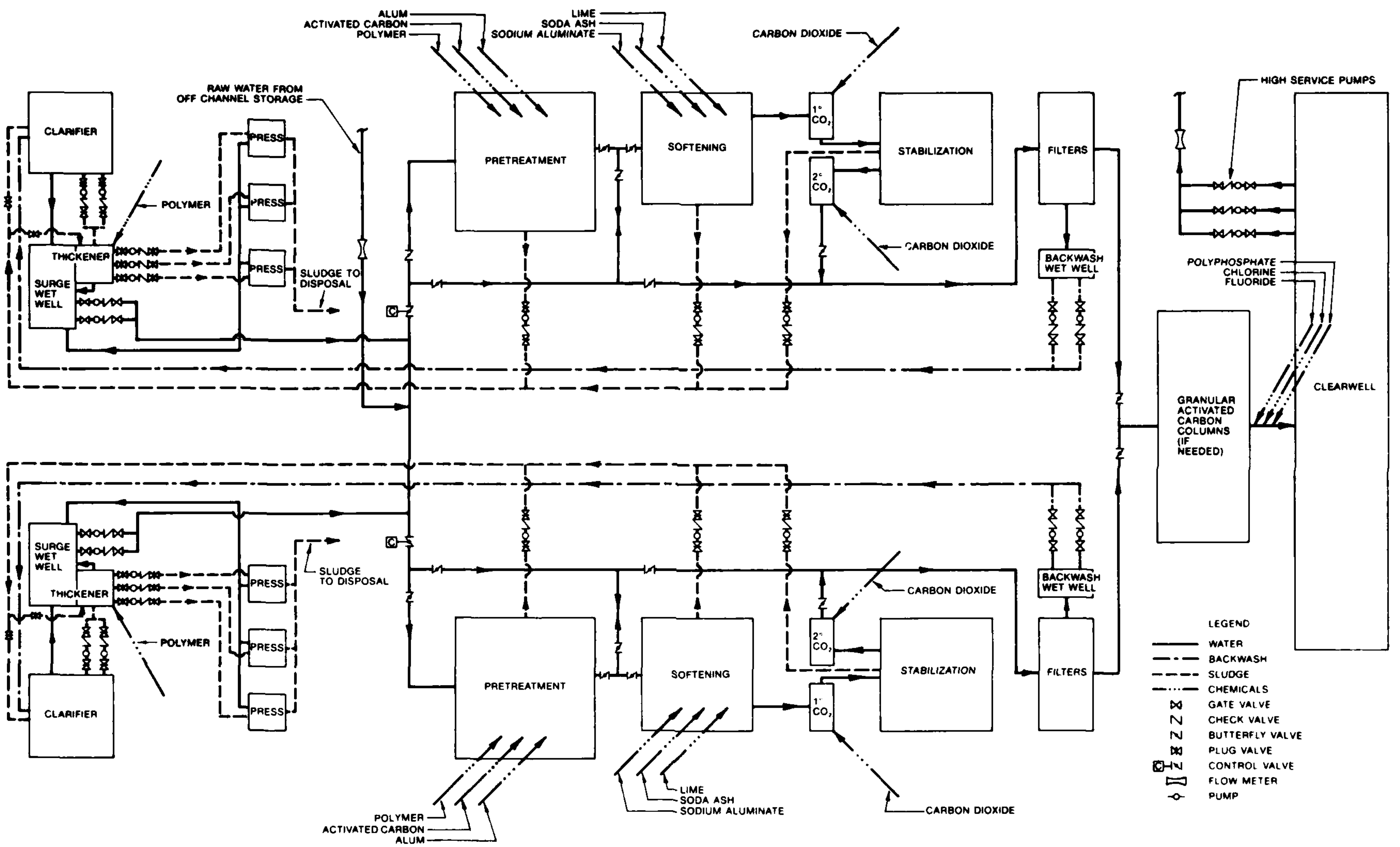
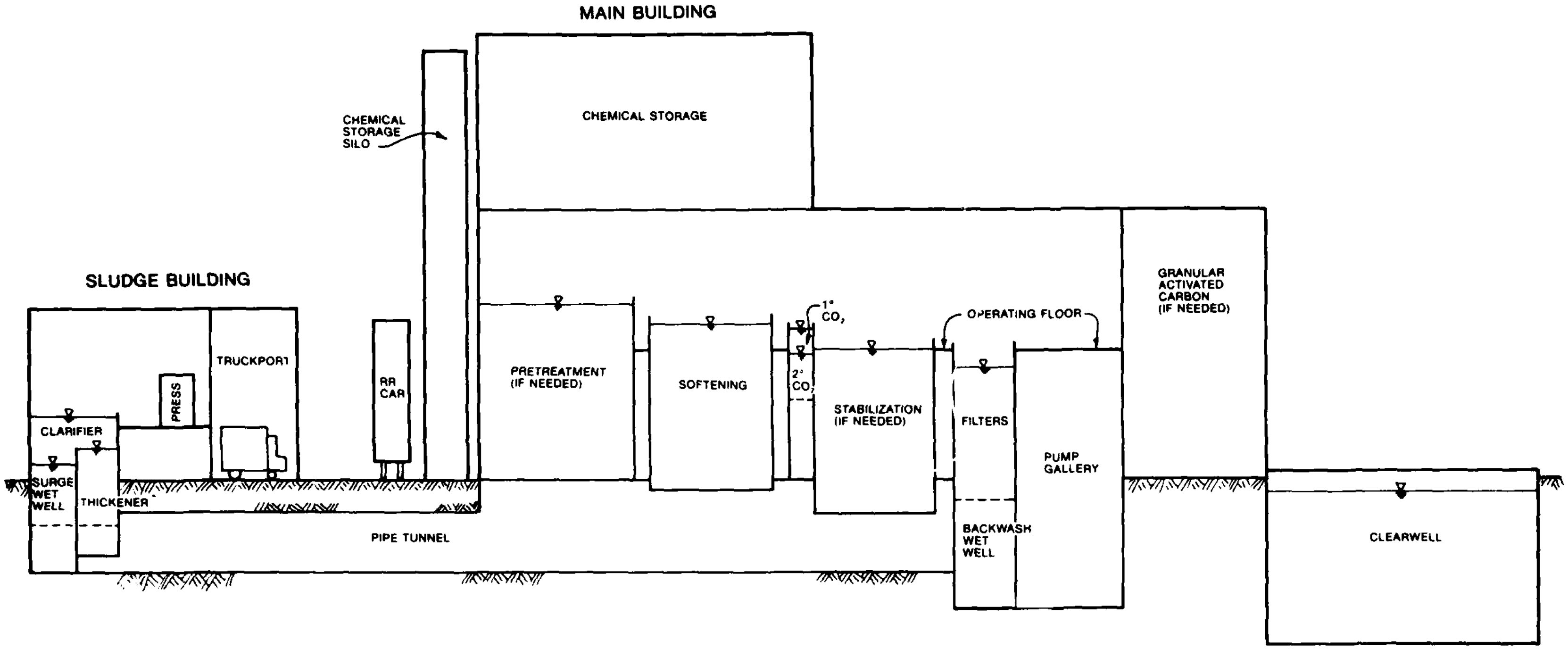


Figure 19 - Typical Water Treatment Plant, Schematic



SECTION A — TYPICAL PLANT SECTION AND HYDRAULIC PROFILE

Figure 20 - Typical
Water Treatment Plant, Section View

The surface water sources to be treated and the proposed treatment processes include the unit processes shown on figure 18 for the typical water treatment plant with the following modifications:

Source	Typical Water Treatment Plant Modification
Red River of the North	No granular activated carbon treatment.
Red Lake River	No stabilization, second stage recarbonation, or granular activated carbon treatment
Combination Red River of the North and Red Lake River	Same as Red River of the North
Garrison Diversion water supplementing the Red River of the North	Same as Red River of the North

Advanced Surface Water Treatment

Advanced surface water treatment is provided to ensure the removal of organic chemical contaminants. This advanced treatment includes the addition of granular activated carbon to the unit processes required for normal surface water treatment for all of the alternative water supply sources. The final requirements for advanced treatment have not been promulgated by the EPA, so the actual requirements are unknown.

As proposed, the EPA regulation would require monitoring of the Grand Forks drinking water for organic chemicals for 1 year. Grand Forks would have to implement the other portions of the proposed regulations in about year 2015 when its population is projected to be 75,000. The urban area population is projected to be 75,000 in about year 2000, so a combined system would be affected sooner by the proposed regulations. East Grand Forks population is projected to be 10,000 in about year 1990; they would be required to monitor for organic chemicals at that time.

The North Dakota and Minnesota Departments of Health personnel believe that organic chemical contaminants will not be a problem for Grand Forks or East Grand Forks. They have indicated that most organic constituents present in the Red River of the North and Red Lakes River

are probably due to natural vegetative decay (leaves and agricultural plant residue). There are no major chemical industries located in the Red River of the North basin near Grand Forks and East Grand Forks, so synthetic organic contaminants should not be a problem. A 1975 survey of organics in Minnesota indicated that two of three sites in the Red River of the North basin do not exceed the TTHM limit of 100 micrograms:[59]

Site	Source	Concentration (microgram/liter)
East Grand Forks	Red Lake River	31
Oslo	Red River of the North	92
Breckenridge	Otter Tail River	156

No explanation was given for the relatively high concentration in the Breckenridge, Minnesota, water. However, the sampling and analytical techniques available in 1975 may be part of the reason.

It is recommended that Grand Forks and East Grand Forks together undertake an organic chemical monitoring program to determine the concentration of organic chemicals in their raw and treated waters. Samples should be collected and analyzed quarterly. This data would provide a sound basis for justifying the need or lack of need for removing organic chemical contaminants by the Grand Forks and East Grand Forks water treatment plants. If research conclusively determines that organic chemicals are hazardous to human health, they must be removed from drinking waters. However, the monitoring results may prove that concentration levels are below safe levels and no additional treatment may be required.

The North Dakota and Minnesota Department of Health personnel have also indicated that most of the organic constituents in the Red River of the North and Red Lake River can probably be removed by chemical addition and sedimentation in the pretreatment basin.

By eliminating prechlorination and removing the organic precursors of trihalomethanes before chlorination, low levels of chlorinated organics (TTHM's) would be present in the drinking waters.

On the basis of the above analyses, granular activated carbon treatment will not be required under the current proposed regulations. However, the requirements may change to include systems serving smaller populations or lower organic chemical contaminant limits. Future monitoring may find that high levels of contaminants are present or may identify other contaminants which must be removed. Therefore, the typical water treatment plant includes the granular activated carbon treatment process.

Groundwater Treatment

For groundwater sources, pretreatment is not required. Both the Elk Valley and Beach Ridge aquifers have similar water quality. Softening is desirable and can be accomplished through a one-stage process. Therefore, the typical water treatment plant shown on figure 18 should be modified by removing pretreatment, stabilization, second-stage recarbonation, and granular activated carbon.

If monitoring of the groundwater source indicates that high organic chemical concentrations are present, advanced groundwater treatments may be needed. Pesticides and herbicides can be sources of organic chemical contaminants. Although none are known to exist, landfills containing organic chemicals could leach into groundwaters. The advanced groundwater treatment probably would include granular activated carbon treatment. Proper management of the aquifer recharge area should eliminate much of the potential for organic contamination; however, groundwaters which are already contaminated would have to be treated. Therefore, advanced groundwater treatment is considered.

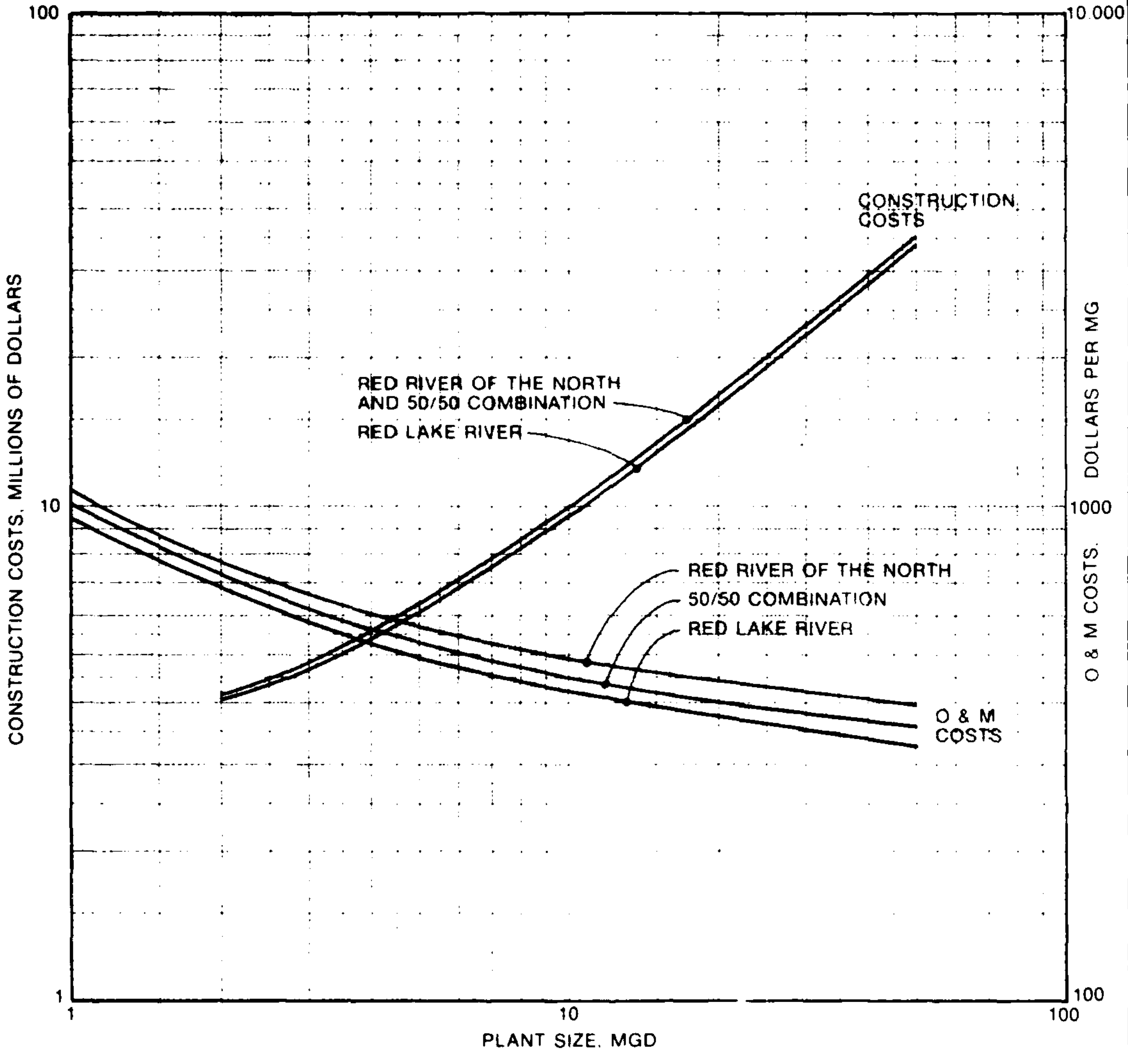
WATER TREATMENT COSTS

Figure 21 for surface water treatment, figure 22 for advanced surface water treatment, and figure 23 for groundwater treatment present cost curves for plants capable of treating the alternative water supply sources. The curves include construction and operation and maintenance costs for a range of treatment plant capacities.

The cost curves were developed through a preliminary design of the typical water treatment plant. The preliminary design was shown on figures 18, 19, and 20. The preliminary design included unit process selection and sizing, plant layout, piping arrangements, hydraulic computations, chemical requirements, and chemical feed and storage equipment sizing. Several equipment manufacturers, the North Dakota and Minnesota Departments of Health, and Stanley Consultants water treatment engineers provided advice and consultation.

Cost estimates of the various water treatment plants were made by obtaining equipment costs from manufacturers and applying unit costs to quantity takeoffs for concrete and buildings. Costs for piping and pumping, site work, electrical, controls, laboratory, offices, and vehicles were also estimated. An undeveloped design detail factor of 15 percent was added to the total estimate costs to develop the probable construction costs.

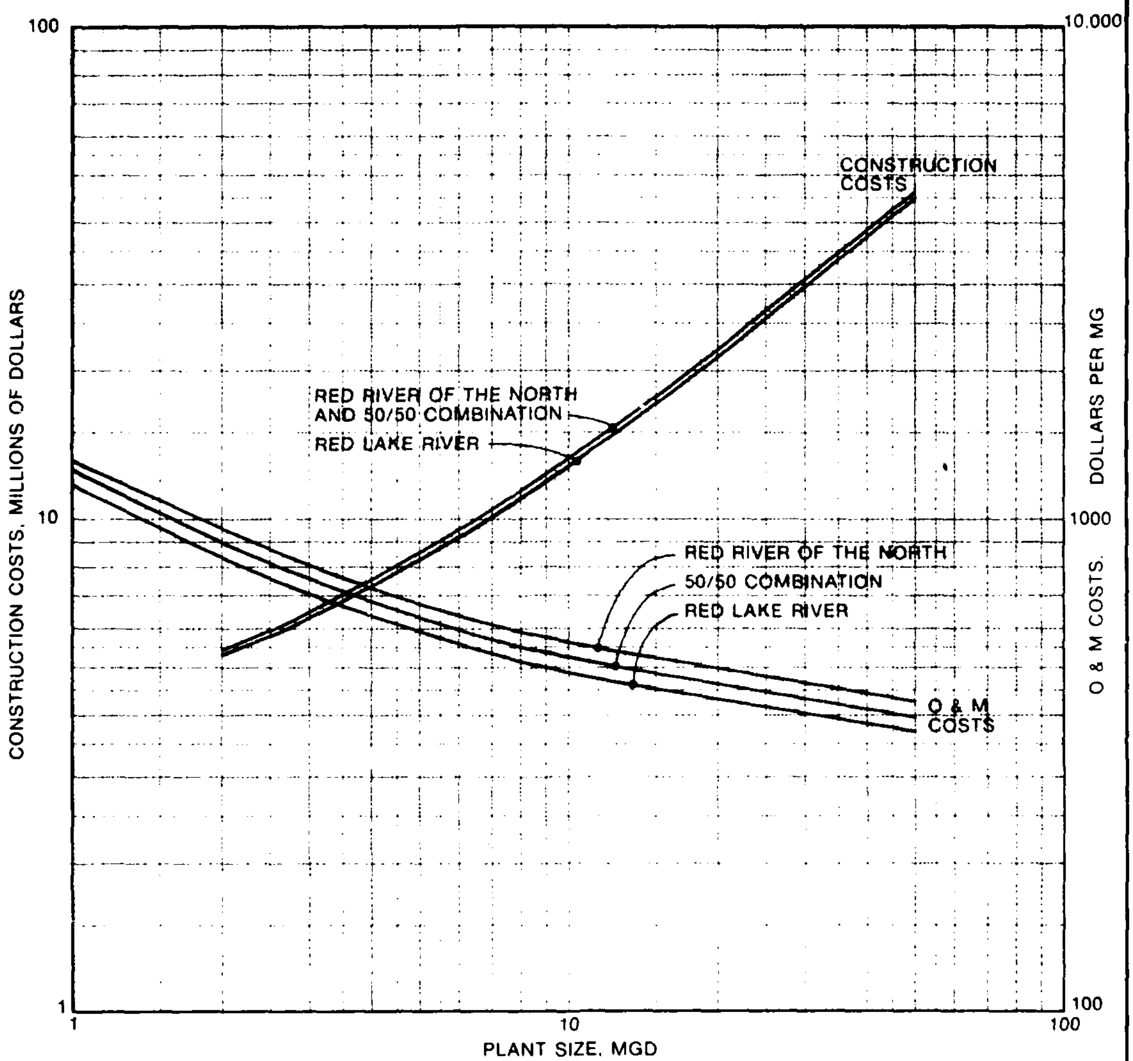
The probable construction costs are used for comparing alternatives; however, other local costs must be added to the probable construction costs to determine the total local financial responsibility. The local costs will include engineering, contingency, legal, and administrative costs which are estimated to be 25 percent of the probable construction costs. Land costs at an estimated $7,000 per acre and interest during construction at about 8 percent will be local responsibilities. The land areas required for various capacity treatment plants are estimated to be:



NOTES:

1. CONSTRUCTION AND O & M COSTS FOR TREATING RED RIVER OF THE NORTH OR COMBINATION OF RED RIVER OF THE NORTH AND RED LAKE RIVER WATER INCLUDE PRETREATMENT AND TWO-STAGE SOFTENING.
2. CONSTRUCTION AND O & M COSTS FOR TREATING RED LAKE RIVER WATER INCLUDE PRETREATMENT AND ONE-STAGE SOFTENING.
3. BASED ON JANUARY, 1979, ENRCCI 2870.0.

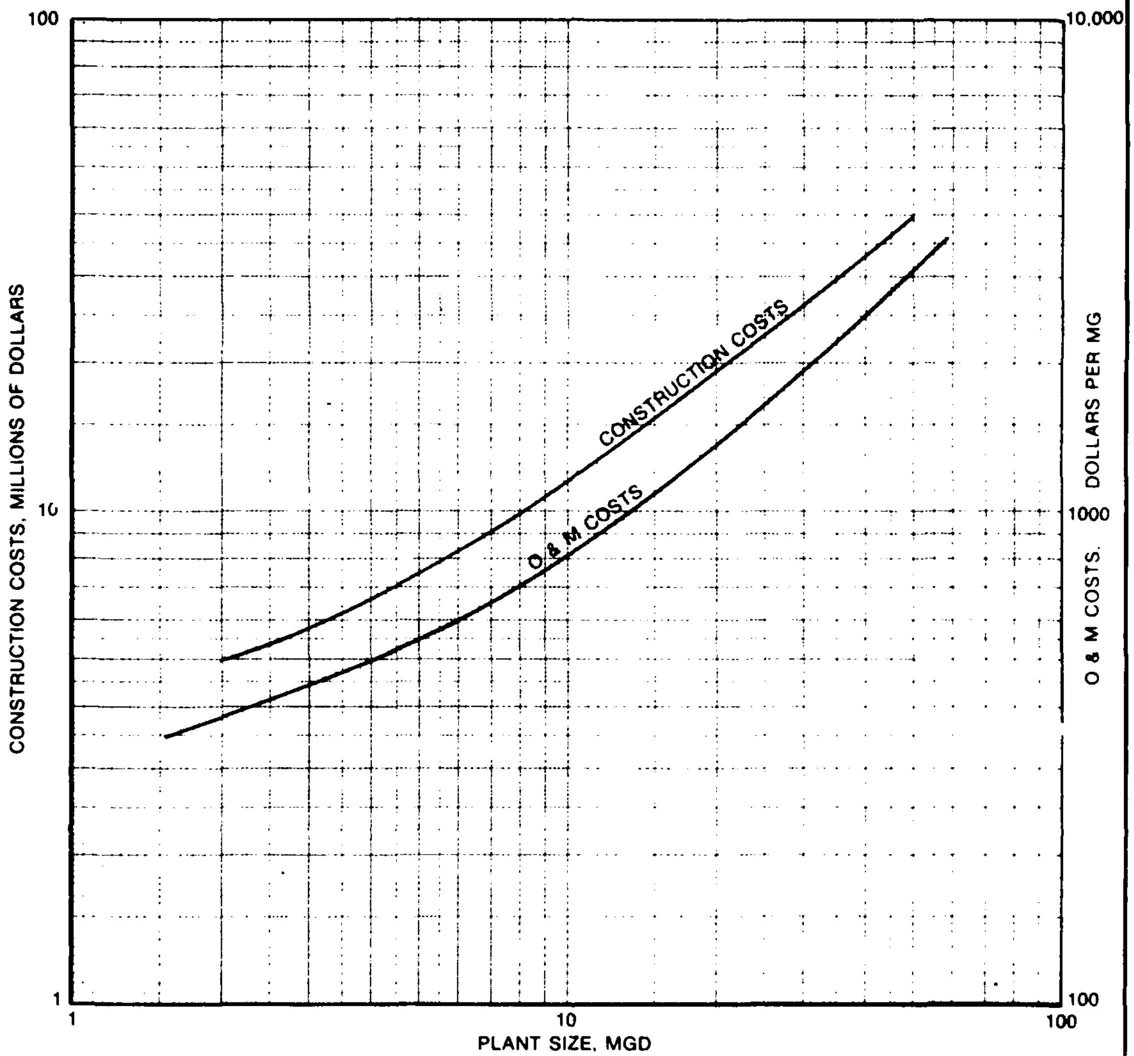
Figure 21 - Surface Water Treatment Costs



NOTES:

1. CONSTRUCTION AND O & M COSTS FOR TREATING RED RIVER OF THE NORTH OR COMBINATION OF RED RIVER OF THE NORTH AND RED LAKE RIVER WATER INCLUDE PRETREATMENT, TWO-STAGE SOFTENING, AND GRANULAR ACTIVATED CARBON TREATMENT.
2. CONSTRUCTION AND O & M COSTS FOR TREATING RED LAKE RIVER WATER INCLUDE PRETREATMENT, ONE-STAGE SOFTENING, AND GRANULAR ACTIVATED CARBON TREATMENT.
3. BASED ON JANUARY, 1979, ENRCCI 2870.0.

Figure 22 - Advanced Surface Water Treatment Costs



NOTES:

1. CONSTRUCTION AND O & M COSTS FOR TREATING ELK VALLEY AQUIFER WATER INCLUDE ONE-STAGE SOFTENING.
2. BASED ON JANUARY, 1979, ENRCCI = 2870.0.

Figure 23 - Groundwater Treatment Costs

Plant Capacity (mgd)	Land Area (acres)
3	4.6
4	5.0
8	6.8
12	8.6
16	10.4
20	12.2
30	15.8

The operation and maintenance cost curves were developed from several sources including EPA reports, wastewater treatment cost curves, and chemical costs.[60,61] The validity of these costs was checked against existing local costs.[62,63] The chemical costs were determined by applying local unit costs to the theoretical chemical usages for the different water qualities considered. The operation and maintenance costs were estimated for each unit process, for chemical feeding, for building energy, and for sludge trucking and disposal.

REGIONAL WATER TREATMENT PLANT SITES

A regional water treatment plant capable of meeting the urban area water demands through year 2030 would have a capacity of 30 mgd and would occupy about 15.8 acres of land. Additional space should be provided for future expansions and flexibility. Water treatment standards may change so additional treatment processes may be required. Future sludge handling processes may include recovery and recycling of lime and alum so additional land may be required. A buffer zone between the plant and residential developments should be provided.

The existing Grand Forks water treatment plant site is surrounded by existing residential and commercial development. Major expansions would require purchase and removal of one or more blocks of residential housing and/or commercial buildings.

Some space for expansion or new treatment processes is available at East Grand Forks.

Figure 24 locates the regional water treatment plant sites evaluated. Table 23 summarizes the evaluation of these potential sites. Each site has various advantages and disadvantages. In addition to the requirement for adequate land area, local officials have placed significant importance on being able to withdraw water from both the Red Lake River and Red River of the North.

On the basis of the evaluation included in table 23, the recommended regional water treatment plant site is Site 4. This site is large enough for expansion and flexibility and relatively close to the Red River of the North and the Red Lake River. The existing Grand Forks Intake No. 1 on the Red River of the North will be modified, but it is more economical to abandon Grand Forks Intakes No. 2 and No. 3 and the East Grand Forks intake. A new intake in the Red Lake River closer to the regional treatment plant site will be built. The preliminary analysis indicates that the regional treatment plant can be connected to the existing Grand Forks and East Grand Forks water distribution systems. However, further analysis of the distribution is needed to determine that adequate water quantities and pressures are available through the distribution systems. If Site 4 cannot be obtained for the regional water treatment plant, one of the other sites evaluated in table 23 or one similar to Site 4 in a neighboring area should be selected.

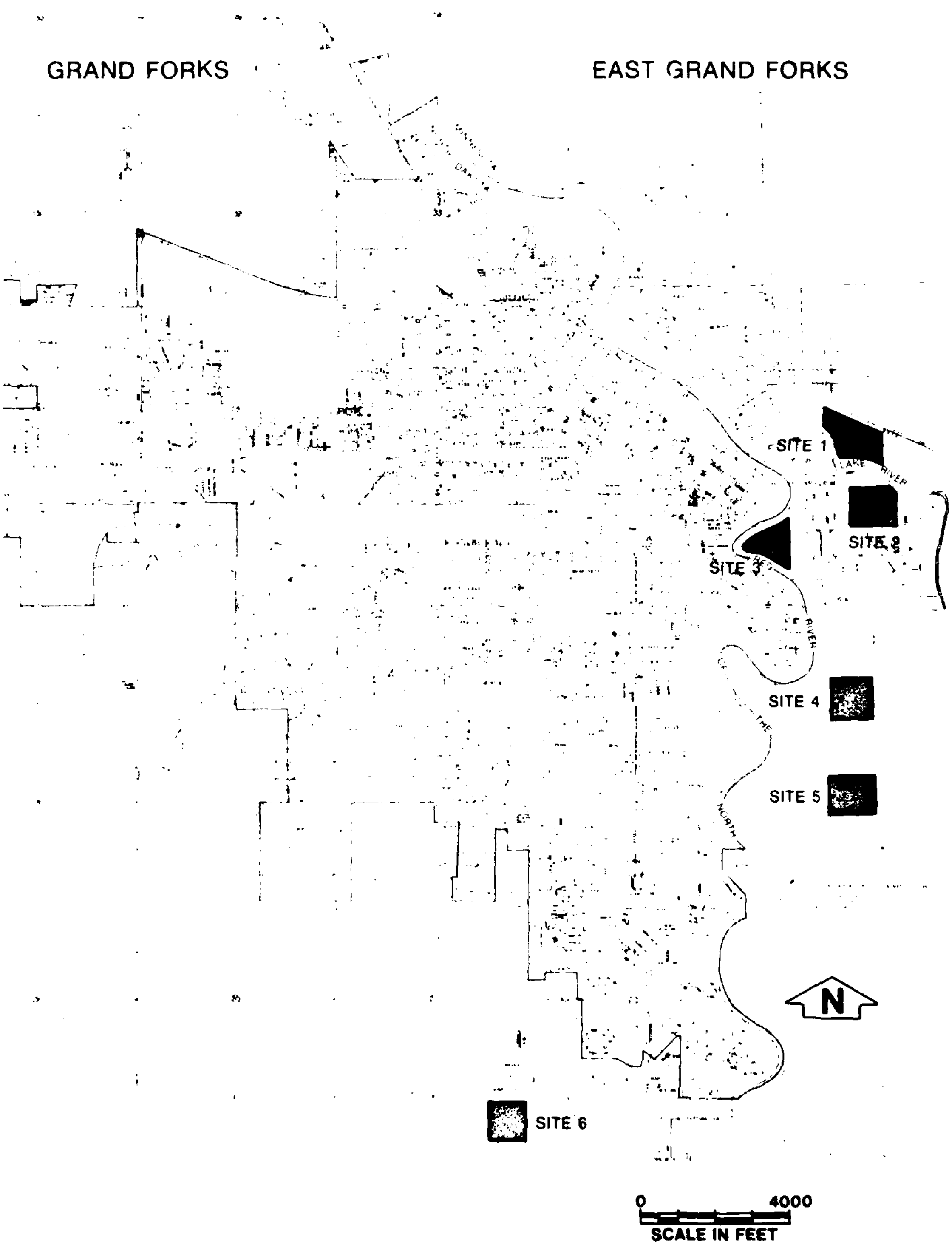


Figure 24 - Regional Water Treatment Plant Sites

Table 23 - Comparison of regional water treatment plant sites

Site	Added Distance From Water Sources	Distance to Distribution Systems(1)	Existing Land Use	Flood Protection Required	Capital Costs(2)(3)	Physical Constraints and Impacts
1	3,000 ft	4,000 ft	Water Treatment Plant	Some	$1,619,000	Space for expansion beyond 30 mgd is limited.
2	6,500 ft	5,000 ft	Park	Some	$2,109,000	Park would be reduced or eliminated. Adjacent to existing residents. Space for expansion beyond 30 mgd is limited.
3	1,500 ft	3,000 ft	Agriculture	Extensive	$3,098,000	Adjacent to existing residents. Space for expansion is limited. Extensive flood protection is required.
4	9,500 ft	5,500 ft	Agriculture	Minimal	$2,941,000	Adequate space for future expansions and requirements.
5	11,000 ft	11,000 ft	Agriculture	Minimal	$4,144,000	Distance from existing distribution systems. Distance from Red Lake River. Adequate space for future expansions and requirements.
6	30,000 ft	10,000 ft	Agriculture	None	$6,116,000	Distance from existing water intakes and Red Lake River. Adequate space for future expansions and requirements.

Notes: (1) Total distance to both Grand Forks and East Grand Forks water distribution systems.

(2) Assumes O&M costs are approximately the same for each site.

(3) Includes current day costs for intakes, raw water pipelines, finish water pipelines to distribution systems, piping connections, piping modifications, and flood protection regardless of the construction timing.

Source: Stanley Consultants

WATER STORAGE AND TRANSMISSION

CENERAL

This section examines the preliminary design of the water storage structures and transmission facilities. The criteria used in the design are presented and cost information for the facilities is developed.

REPLACEMENT OF LOW-HEAD DAMS

The first consideration is to preserve the existing in-channel storage capacity. Water is pooled behind the existing low-head dams located on the Red River of the North and the Red Lake River. Water intakes for Grand Forks, East Grand Forks, and the self-supplied industries are located in these pools. Also, the in-channel storage helps supply water demands during low river flows.

The present low-head dam across the Red River of the North lies approximately 550 feet upstream from the USGS stream gaging station and approximately 4,350 feet downstream from the U.S. Highway 2 bridge. The dam was built in 1925 as a rock-filled timber-crib structure. Between 1925 and 1976 the dam was repaired several times. There are no records readily available that indicate the condition of the dam during the 1930's drought. The North Dakota State Water Commission performed and financed extensive repair work to the structure in 1978 to prevent possible failure and because a majority of the river flow was passing through the dam rather than over it. The repair work consisted of grouting voids within the dam and constructing a concrete apron on the downstream side of the dam. North Dakota State Water Commission personnel indicated that the

cost for the repair work was $136,800. The useful life of the dam following renovation is projected to be about 12 years, or through year 1990. In September 1977, the North Dakota State Water Commission and the city of Grand Forks entered into an agreement for investigations to preliminarily design and cost a new dam to replace the Riverside Park Dam. It is anticipated that a report on the investigations will be completed in 1981.

Age, design details, and present conditions of the low-head dam across the Red Lake River are not currently available. However, this dam is probably similar to the Red River of the North low-head dam. This dam is located about 800 feet upstream from the confluence of the Red Lake River with the Red River of the North and about 400 feet downstream from the Minnesota Highway 220 bridge. It is projected that this low-head dam should be replaced in 1990.

Figure 25 shows the plan and cross-sectional details of a typical low-head dam. The estimated construction cost for the low-head dam is $1,900,000 for a 200-foot long structure. Average operation and maintenance costs are estimated to be $20,000 every 5 years including maintenance of riprap.

The crest elevation of the new dams will be the same as the existing structures. Preliminary analysis indicates that the Red River of the North storage pool extends approximately 37.5 miles upstream from the dam and has a storage capacity of about 2,200 acre-feet. This estimated capacity includes an allowance of 5 feet for sediment buildup between high-flow scours. The Red Lake River storage pool extends approximately 12.5 miles upstream and has a storage capacity of about 1,000 acre-feet.

The geology of the area typically includes shallow alluvium deposits underlain by lacustrine sediments to depths of 140 feet before glacial till is encountered. These materials form a permeable bottom material upon which the dam will be built.

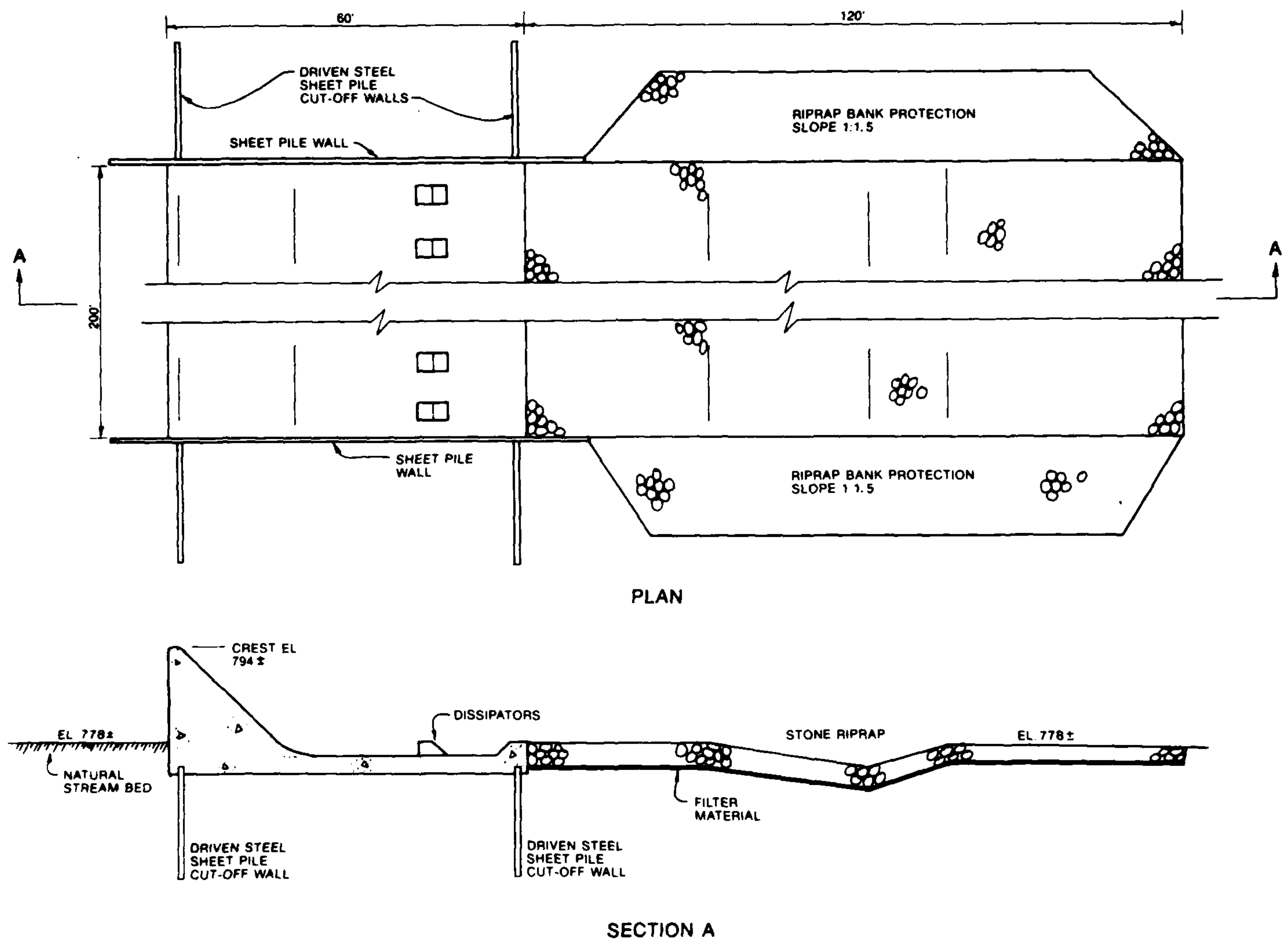


Figure 25 - Typical Low-Head Dam

Therefore, it will be necessary to drive sheet pile cutoff walls below and at the ends of the dams. North Dakota State Water Commission personnel indicated that cutoff walls are typically driven to depths of 20 feet on this river.

OFF-CHANNEL STORAGE

Previous analyses of water supply sources indicate that the Red River of the North and Red Lake River flows along with existing in-channel storage can satisfy the GF/EGF urban area water demands. However, some local concern still exists. An off-channel storage reservoir could be used as a supplemental water source during periods of poor water quality in the rivers. However, the costs for providing off-channel storage are relatively high.

Figure 26 locates the five most promising off-channel storage reservoir sites identified. Twenty potential off-channel storage reservoir sites were originally considered. These sites were either relatively close to the two rivers or the urban growth areas and were relatively open areas. The major reasons for eliminating potential sites from further consideration were long distances from the urban areas, relatively small areas, difficulties in fully utilizing the site, and the presence of relatively large forested areas.

Table 24 summarizes the analyses of the most promising alternatives. Each site has various advantages and disadvantages. Adequate area must be available to provide enough storage capacity; therefore, the sites are located on large, relatively flat areas. Unfortunately, these sites are also prime agricultural and/or development lands.

Few oxbows exist near the GF/EGF urban area. Artificial oxbows could be created by dredging new river channels between river meanders. However, the available storage capacity in the natural or artificial oxbows is limited and much smaller than

Table 24 - Comparison of off-channel reservoir sites[1]

Site	Location			Existing Land Use	Land Ownership	Distance to Water Treatment Plant		Constraints and Impacts
	County	Township	Section			GF	EGF	
1	Grand Forks	Grand Forks	28	Agricultural	3 parcels	4.0 miles	4.6 miles	No buildings involved. Gas pipeline is located on extreme west side of the section. Power line traverses east side of the section.
5	Polk	Huntsville	30	Agricultural and Some Residential	16 parcels	4.3 miles	4.4 miles	Six houses to be relocated. Four other buildings to be removed. Power line traverses east one-third of the section.
2	Polk	Grand Forks	13 & 24	Agricultural and Residential	32 parcels	0.9 miles	1.7 miles	Nineteen houses to be relocated. Sixteen other buildings to be removed.
3	Polk	Huntsville	9	Agricultural	5 parcels	3.2 miles	2.4 miles	Two houses to be relocated. Six other buildings to be removed.
4	Polk	Huntsville	21 & 27	Agricultural and Some Residential	3 parcels	5.2 miles	4.6 miles	Six houses to be relocated. Six other buildings to be removed.

Note: 1. Based on about 640 acres of reservoir site. This total area is based on Stage 2 study results which indicated that a relatively large storage volume would be needed.

Source: Stanley Consultants

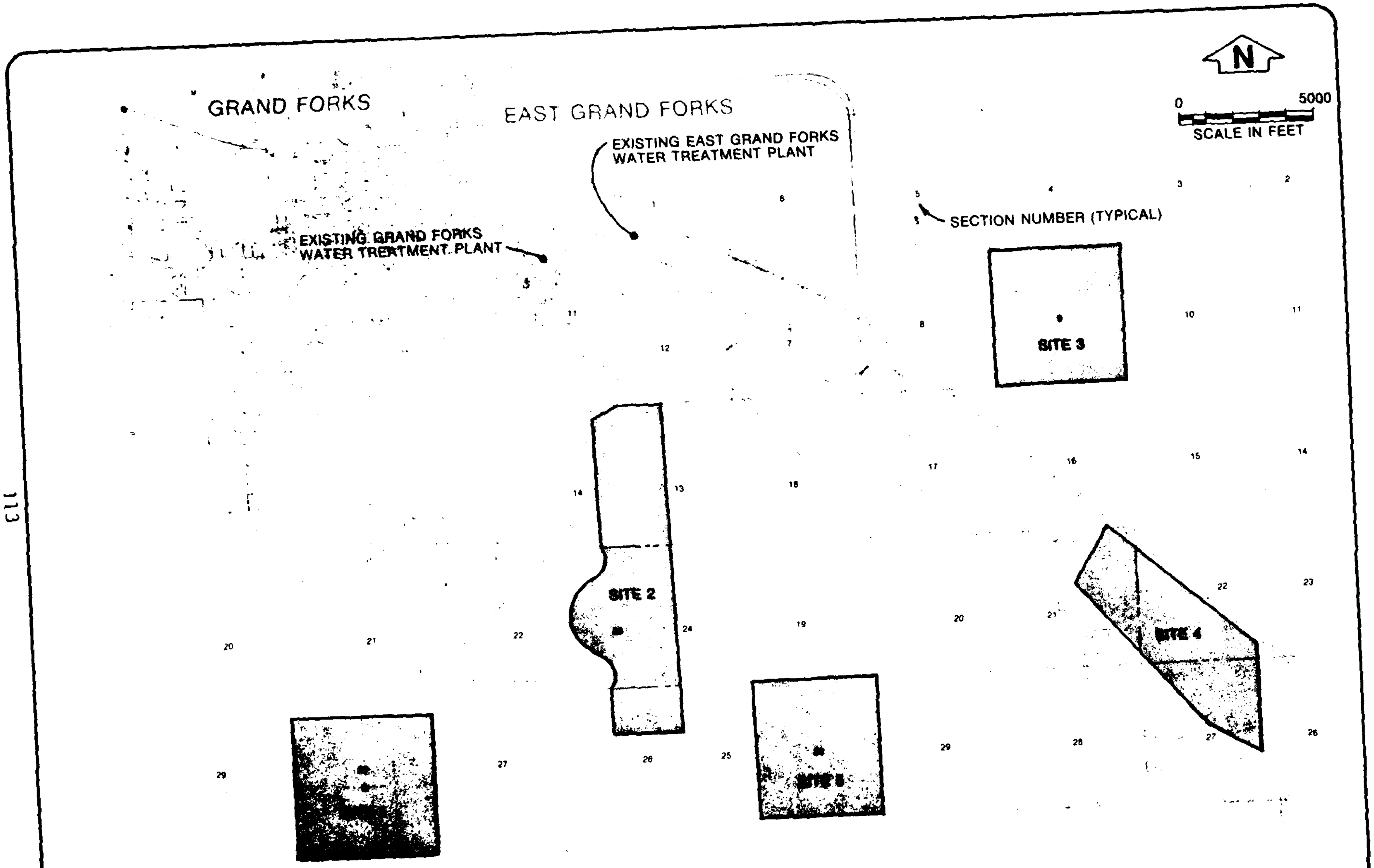


Figure 26 - Off-Channel Storage Reservoir Sites

needed. Excavating the land knob within the oxbow would increase the storage capacity. High costs are associated with excavating and wasting this material.

Figure 27 shows a typical off-channel storage arrangement and cross-section view. Construction would involve stripping away approximately 12 inches of topsoil. Earth embankments with 3 to 1 side slopes would be constructed from excavated material within the reservoir. The embankment crest width would be 10 feet to allow vehicle access. A 50-foot wide easement around the toe of the embankment is provided for access. A 3-foot freeboard between the peak water surface elevation and the embankment crest elevation is allowed. A soil sealant may be needed to prevent seepage losses. Depending upon soil analysis, the seal may be needed for either the inside faces of the embankment or for the embankment and the bottom of the reservoir. The sealant would be bentonite spread at a density of 25 tons per acre and disked into the top 6 inches of soil.

Analysis of reservoir water depth and fetch characteristics indicates that the maximum probable wave height occurring on the reservoir would be about 2.5 feet. Waves of this height would pose a threat to the stability of the embankment; hence, riprap protection of the inside face of the embankment is required. Rough angular stone with an average weight of 50 pounds and diameter range of 9 to 15 inches should be laid to a depth of approximately 24 inches for a distance of 30 feet down the inside face of the embankment.

The effects of sediment buildup in the reservoir were considered in the preliminary design. Sediment production in the reservoir has been estimated at 0.1 foot per year. The sediment may be removed at regular intervals, or sufficient excess capacity in the reservoir may be provided to accommodate the sediment. Analysis showed that dredging of sediment at regular intervals

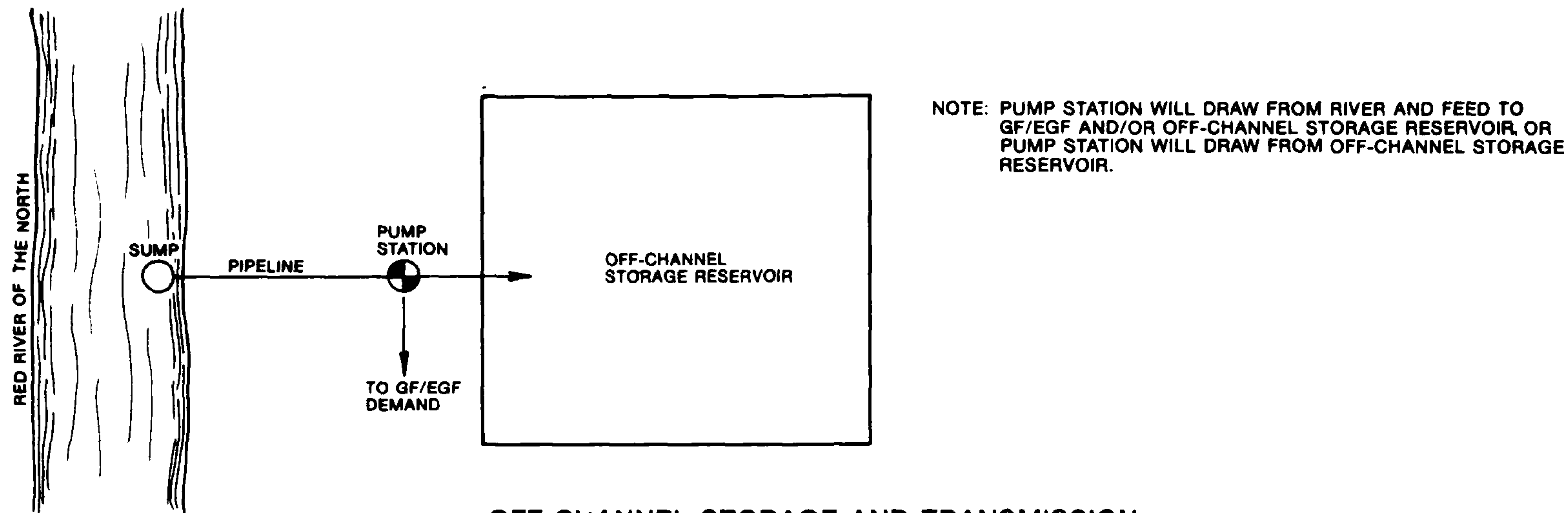
was prohibitively expensive compared to constructing the reservoir with additional capacity. Hence, an additional 5 feet of depth is allowed in the reservoir to accommodate sediment for the 50-year life of the structure. The total depth of the reservoir would be 23 feet (3 feet for freeboard, 15 feet for water storage, and 5 feet for sediment allowance).

Figure 28 presents the cost curves for construction and operation and maintenance of a typical off-channel storage reservoir. A range of off-channel storage capacity was considered. Reservoir sizing will depend upon local desires. For example, a reservoir capacity of 2,100 acre-feet would be required to satisfy the average GF/EGF water demands for 30 days in year 2030. This capacity is based on an average demand of 25.57 cfs, surface water evaporation of 28 inches per year, and sedimentation estimated at 0.1 foot per year. Approximately 135 acres of land will be required for this size storage reservoir.

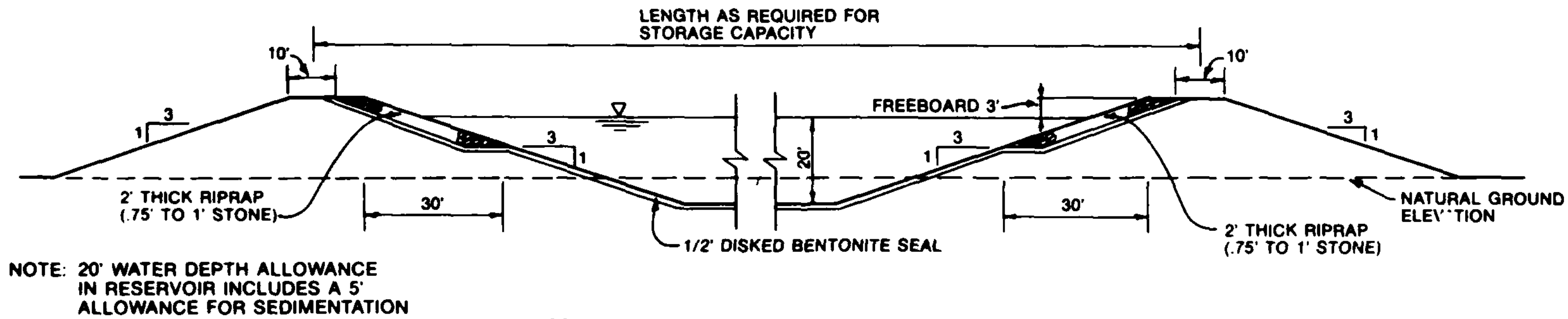
The cost curves were developed through a preliminary design of a typical off-channel storage reservoir. Volumes and areas of materials required were calculated and unit costs were applied to quantity takeoffs for land acquisition, topsoil stripping and grubbing, earthwork, bentonite seal (if needed), riprap protection, and grass and landscaping. An undeveloped design detail factor of 20 percent was added to the total estimated costs to develop the probable construction costs. Land requirements vary from about 40 acres for 500 acre-feet of storage to 900 acres for 10,000 acre-feet of storage. O&M cost curves were based on maintaining the embankments, riprap, sealant, and grounds.

TRANSMISSION

A water transmission system is needed to deliver water from its source to the treatment plant and/or storage reservoir. The transmission system includes both pumping stations and pipelines and associated intake valves, wet wells, and control structures.

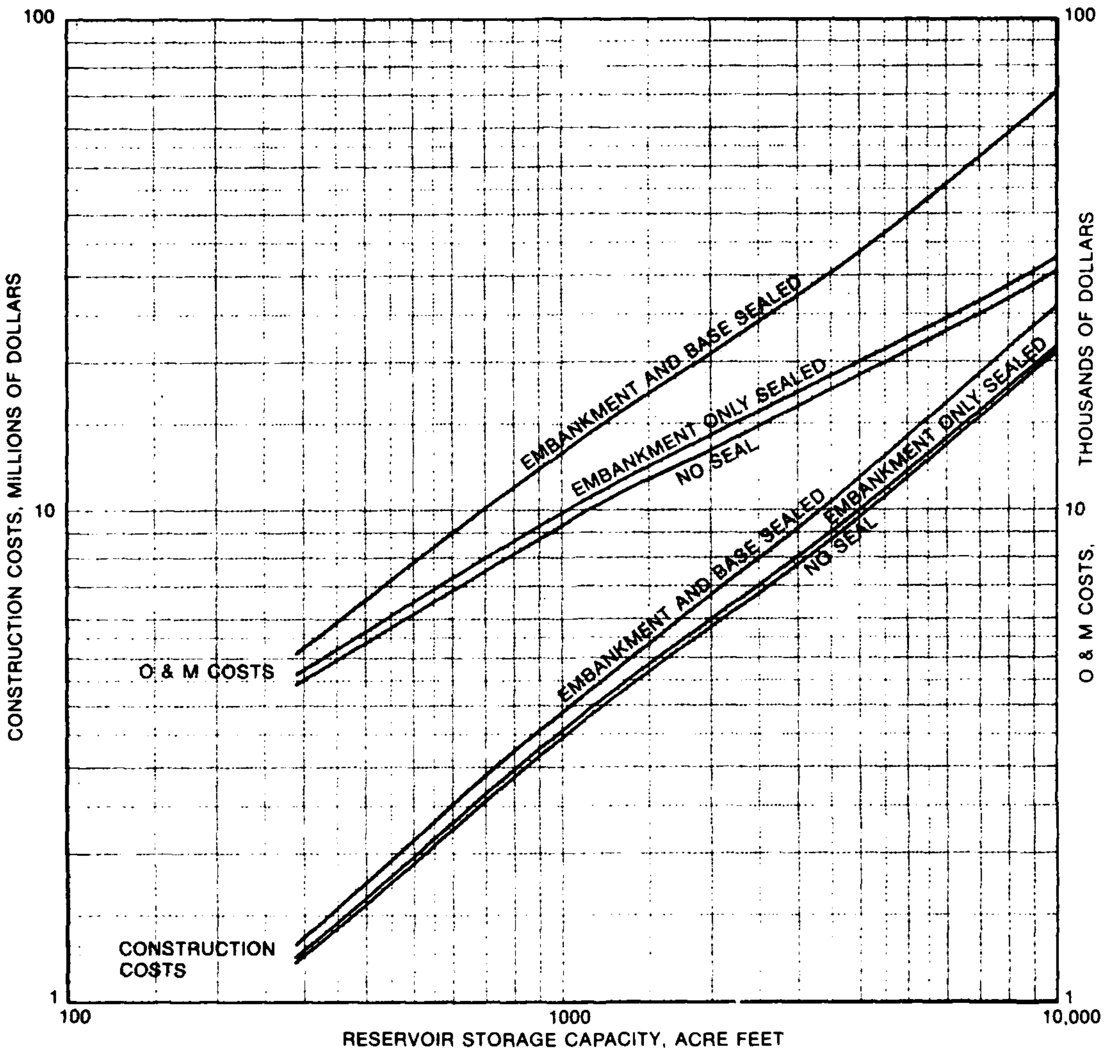


OFF-CHANNEL STORAGE AND TRANSMISSION



TYPICAL OFF-CHANNEL STORAGE RESERVOIR CROSS-SECTION

Figure 27 - Typical Off-Channel Storage Reservoir



COSTS BASED ON: 1. 15' WATER DEPTH, 3:1 SIDE SLOPES; 3' FREEBOARD; 5' ALLOWANCE FOR SEDIMENTATION.

2. JANUARY, 1979, ENRCCI = 2870.0.

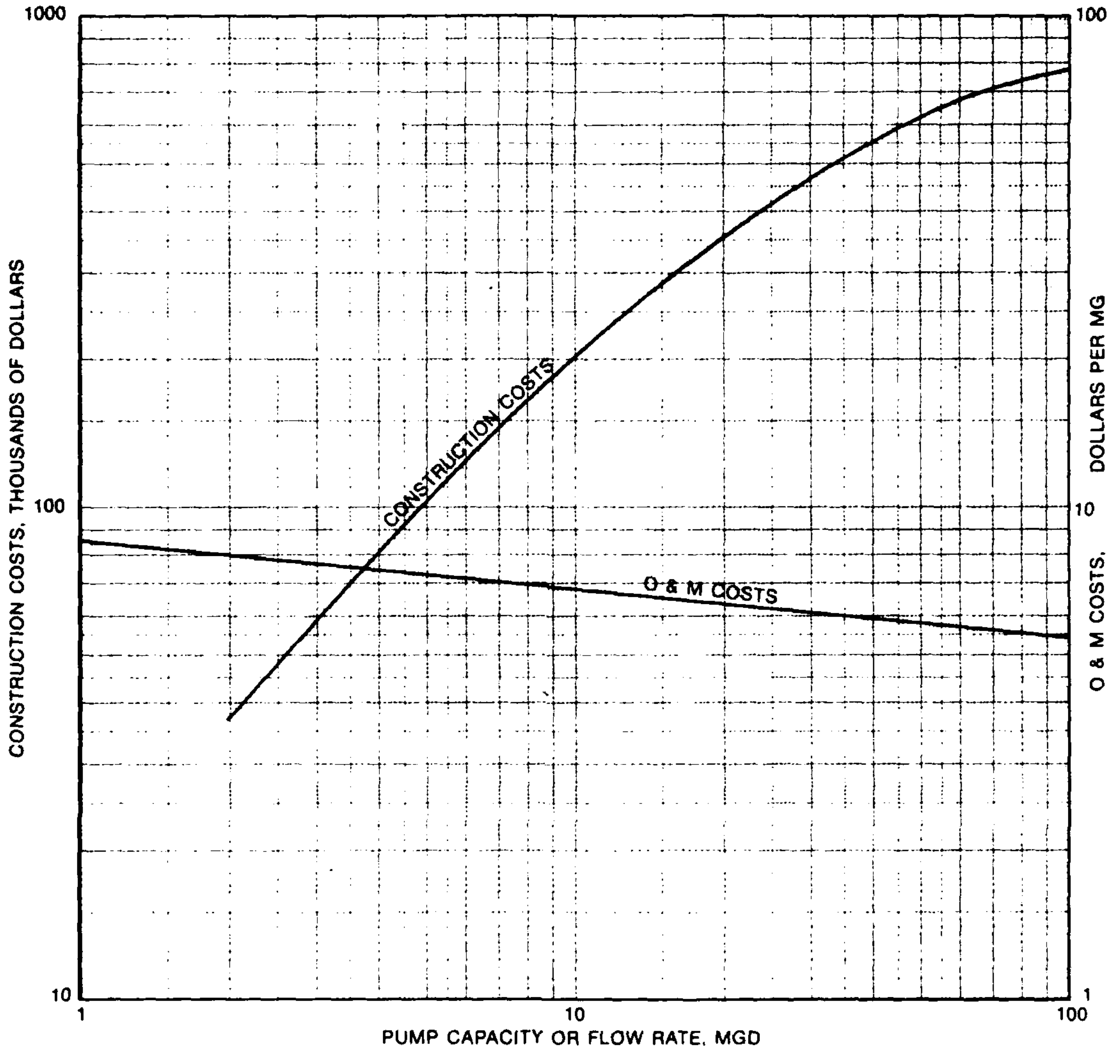
COSTS INCLUDE: 1. LAND AQUISITION, EXCAVATION, BANK CONSTRUCTION SEALING, RIPRAP, BANK PROTECTION, FENCING.

Figure 28 - Off-Channel Storage Reservoir Costs

Transmission pipelines are also needed if the treatment plant is located a substantial distance from the distribution system.

Figure 29 presents cost data for pump stations. The pump station costs are based on preliminary designs and include wet well, pumps, intake-outlet structures, building to house the facilities, and electrical requirements. An allowance of 20 percent for undeveloped design details has been added to the total cost estimates to give the probable construction costs. O&M costs were obtained from EPA cost curves.[60] The curves give the costs for pumping rates ranging from 10 to 100 mgd.

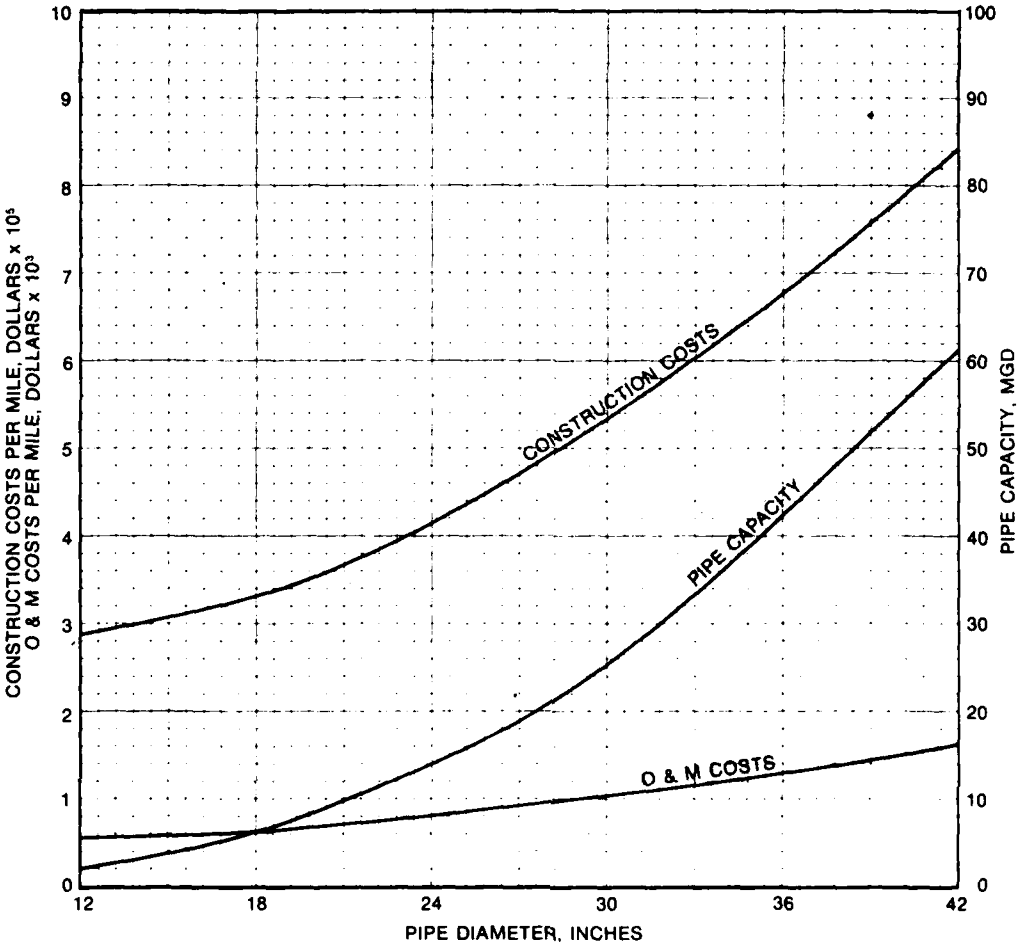
Figure 30 gives cost data for transmission pipelines. Curves include trenching, pipe, valves, surface restoration, and encounters with roads and utilities. The costs presented are in dollars per mile of pipe laid. Undeveloped design details are again assessed at 20 percent of the costs estimate. Annual O&M costs are estimated to be 0.2 percent of the construction costs.



COSTS BASED ON: 1. 50' HEAD LOSS.
2. JANUARY, 1979, ENRCCI = 2870.0.

COSTS INCLUDE: 1. PUMP HOUSE, PUMPS, SUMP, INTAKE, AND OUTLET.

Figure 29 - Pump Station Cost



COSTS BASED ON: 1. PIPE CAPACITY CALCULATED FOR A PIPE WITH C = 100, HEAD LOSS = 10'/1000'.

2. JANUARY, 1979, ENRCCI = 2870.0.

COSTS INCLUDE: 1. TRENCHING, PIPE, VALVES, SURFACE RESTORATION.

Figure 30 - Transmission Pipeline Costs

INSTITUTIONAL ANALYSIS

GENERAL

A wide range of Federal, State, regional, and local agencies are directly involved in or have authority over water resources in the Grand Forks-East Grand Forks urban area. These agencies are responsible for implementing the water supply, storage, transmission, and treatment alternatives discussed in the three previous sections. The water resource agencies have the institutional authority to plan, design, finance, construct, and regulate water supply systems. These agencies are analyzed in this section.

The information presented in this section was obtained from the institutional analysis that is summarized in the Stage 2 Background Information Appendix. That report discussed the institutional framework for several water resource programs including water supply, flood control, water quality, fish and wildlife, and recreation. This section discusses only those agencies which have water supply and treatment responsibilities. The Stage 2 Background Information Appendix analyzes all institutions within the study area including rural water systems, small communities, counties, townships, and soil and water conservation districts. Only those agencies which would be directly involved in the alternatives evaluated in this stage 3 report will be discussed.

EXISTING INSTITUTIONAL FRAMEWORK

Table 25 summarizes the applicable water resource agencies and their authority and capabilities. These agencies could be involved in the management of the water supply and treatment alternatives considered.

Table 25 - Water resources agencies

Agency	Authority	A	B	C	D	E	F	G	Functional Concerns
		Existing Capabilities(1)							
FEDERAL									
Army Corps of Engineers	Water Supply Act of 1958	X	X					X	Water supply storage may be provided in Corps-operated reservoirs
	Resolution of Committee on Public Works, U.S. Senate, 30 September 1974	X	X				X	X	Authorized GF/EGF Urban Water Resources Study.
Environmental Protection Agency	The Safe Drinking Water Act of 1974	X						X	EPA has promulgated the National Interim Primary Drinking Water Regulations on Radionuclides, and has proposed regulations on Control of Organic Chemical Contaminants in Drinking Water and on National Secondary Drinking Water Regulations. All public water systems must comply with these regulations.
Economic Development Administration	Public Works and Economic Development Act of 1965	X					X	X	EDA provides loans and matching grants for water treatment facilities and water storage reservoirs to local communities.
Department of Housing and Urban Development	Housing Act of 1954	X					X	X	HUD makes grants to supplement state and local funds for water supply projects that are part of a comprehensive community plan.
Geological Survey	Geological Survey "Organic" Act of 1879	X	X					X	Geological Survey investigates existing and potential water problems, investigates floods and droughts, hydrology and related sciences and provides technical assistance to federal, state, and local agencies.
Upper Mississippi River Basin Commission (Souris-Red-Rainy Regional Committee)	Water Resources Planning Act of 1965	X	X					X	The committee develops plans and regionwide priorities for conservation, development, and utilization of water and related land resources within the Souris, Red, and Rainy River basins.
STATE									
Minnesota Commissioner and Department of Health	Minnesota Statutes 144.05; 144.12; 144.381-.388; and 115.71-.82	X	X					X	The commissioner through the Department of Health examines plans for public water supplies, sets standards for public water systems and water wells, advises on water supply development and water treatment, and conducts analysis on water.

Table 25 (cont)

Agency	Authority	Existing Capabilities (1)							Functional Concerns
		A	B	C	D	E	F	G	
Minnesota Department of Natural Resources	Minnesota Statutes 84 and 105	X	X	X	X	X		X	DNR issues permits for water use, for lake and stream bed use, and for bridge crossings; conducts hydrologic data and water resources studies; operates state-owned dams; develops water resources conservation programs; and prepares reports on water management programs.
Minnesota Water Resources Board	Minnesota Statutes 105.71	X	X					X	The board has the authority to decide questions of water policy where use, disposal, pollution or conservation of water are involved. The board also has jurisdiction over the establishment of watershed districts.
North Dakota Department of Health	North Dakota Statutes 61-28.04	X	X					X	The Department of Health reviews plans of local communities to assure proper construction and safe operation of drinking water facilities; sets standards for public water systems; advises on water supply development and water treatment; and conducts analysis on water.
North Dakota State Water Commission	North Dakota Statutes 61-02	X	X	X(2)	X	X	X	X	The State Water Commission has jurisdiction over all water and water resources projects in the state; issues permits for water use; regulates, finances, constructs, and maintains stream channels, dams, and reservoirs; impounds water for municipal, industrial, and rural water supplies, and provides water for irrigation, livestock watering, power generation, and industrial purposes; and conducts ground and surface water planning and development studies.
REGIONAL									
Grand Forks County Water Management and Control Board, North Dakota	North Dakota Century Code Section 61-16-11	X	X	X	X	X	X		The district is authorized to plan, locate, construct, modify, repair, maintain, and regulate water management facilities within the district.
Red Lake Watershed District, Minnesota	Minnesota Statutes 112	X	X	X	X	X	X	X	The district regulates all water management projects within the Red Lakes watershed.
LOCAL									
Grand Forks, North Dakota	North Dakota Century Code Section 40-05.1	X	X	X	X	X	X	X	Grand Forks provides water supply to city residents and businesses, and supplies water to the Grand Forks Air Force Base.

Table 25 (cont)

Agency	Authority	Existing Capabilities(1) A	B	C	D	E	F	G	Functional Concerns
East Grand Forks, Minnesota	Minnesota Statutes 412	X	X	X	X	X	X	X	East Grand Forks provides water supply to city residents and businesses.
Grand Forks Air Force Base Environmental Support	U.S. Air Force	X	X	X	X	X	X	X	Environmental support provides water supply to the air base.
Emerado, North Dakota	North Dakota Century Code Section 40-05-01	X	X	X	X	X	X	X	Emerado provides water to its residents and businesses.

Notes: (1) Capabilities are A - Policies, B - Planning, C - Property Acquisition, D - Construction, E - Maintenance, F - Financial Assistance, and G - Manpower Assistance.

(2) It is not the policy of the North Dakota State Water Commission to acquire property for projects.

Source: Reference 2

In general, the State and Federal water resource agencies use their financial and manpower resources for policy setting, planning, and regulatory functions. Some financial assistance is available for specialized purposes. Some construction and maintenance functions can be performed within specified limits. However, these agencies do not specifically construct and operate water supply and treatment systems for communities.

The U.S. Army Corps of Engineers (Corps) operates the major reservoirs in the Red River of the North basin. The operating functions of these multipurpose reservoirs include low-flow augmentation for water supply and pollution control and high-flow storage for flood control. Therefore, the Corps plays an important role in supplying water during low-flow conditions caused by droughts. In addition, the Corps is conducting this urban water resources study which includes long-range planning to ensure an adequate water supply for the urban area.

The U.S. Environmental Protection Agency (EPA) also plays an important role in water supply by setting water quality standards which must be met by public water systems. Both the North Dakota and Minnesota Departments of Health have accepted from EPA the responsibility for implementing the water quality standards.

The Federal Economic Development Administration (EDA) and Department of Housing and Urban Development (HUD) have grant monies available which can be used for water supply and treatment projects that meet specific requirements. EDA grants are issued and administered through the Northwest Regional Development Commission in Minnesota and the Red River Regional Planning Council in North Dakota. EDA loans and matching grants must be used for direct economic growth such as providing a public water

supply to an industry or an industrial park. To be eligible for EDA money, the county must be qualified and have completed an Overall-Economic Development Plan. HUD grants are limited to urban renewal and development projects that are part of a comprehensive community plan.

The U.S. Geological survey is primarily an information gathering and dissemination agency. It does investigate and provide advice on water resource projects, but does not have regulatory functions.

The Upper Mississippi River Basin Commission, Souris-Red-Rainy Regional Committee, is primarily a policy setting and basin planning agency. This commission coordinates planning efforts in the basin and helps establish priorities on a basin-wide approach.

At the State level, the Minnesota and North Dakota Departments of Health are concerned with the safety of drinking water supplies and treatment. They have the responsibility for water quality standards, water treatment design criteria, and review of plans and specifications for water supply and treatment facilities. Neither department has the authority to construct, operate, or finance water supply projects.

The North Dakota State Water Commission and the Minnesota Department of Natural Resources have jurisdiction over the waters of their respective States and allocate the use of those waters through permit systems. These agencies conduct investigations and planning studies on surface water and groundwaters. They also may finance, construct, and operate State-owned dams and reservoirs. The North Dakota State Water Commission can fund water resources study and construction projects. The commission completed repair of the Riverside Park low-head dam on the Red River of the North during the fall of 1978. The commission has the authority to acquire property but has established a policy that the local project sponsor must acquire the necessary property and rights-of-way.

Several regional governmental agencies have the authority to provide water supply services. These include the Grand Forks County Water Management District which has the authority to plan, construct, and operate water conservation devices, reservoirs of less than 12.5 acre-feet, flood control facilities, recreational facilities which are adjacent to their water resource developments, and water supply and sewage treatment systems. The district may modify watercourses and regulate streamflows for flood control and water conservation projects. Although the district had an operating budget of $144,000 in 1976-77, they have no full-time staff. They are not currently providing water supply services to any residential, commercial, or industrial users.

Another regional agency is the Red Lake Watershed District which has its office in Thief River Falls, Minnesota. This district encompasses portions of 10 counties which drain to the Red Lake River and has the authority to plan, construct, and operate dams, dikes, water supply systems, and appurtenant works. The district employs two engineers to develop projects and to review applications received by the Minnesota Department of Natural Resources which affect the regulation, conservation, and control of the use of water within the district. The watershed projects include monitoring runoff characteristics through a stream gaging program, investigation of rivers needing dredging and potential impoundment sites, and financing of flood control structures, drainage ditches, and river drainage. The district is not currently providing any water supply services.

At the local level, many governmental agencies have the authority to provide water supply and treatment services within their jurisdictions. Rural water associations currently have the authority to provide water to residents outside existing municipal water system service areas. Grand Forks and Polk Counties and the townships in Polk County have legal authority to provide potable water services, but none of the entities have

exercised this authority. The communities of East Grand Forks, Grand Forks, and Emerado provide water supply services.

East Grand Forks, Minnesota, supplies water to the residents and businesses within its corporate boundaries. The city has the authority to establish, regulate, finance through tax levies and bond issues, assess rates, and operate water supply, treatment, storage, and distribution systems. The city's Water, Light, Power, and Building Commission supervises the water system. The city does not provide water services beyond its boundaries; however, the city has cooperated with Grand Forks and provided an interconnection between the two cities' distribution systems. This connection has not been used to date, and there is no written agreement covering this interconnection.

Grand Forks, North Dakota, provides water to users within its corporate boundaries and to the Grand Forks Air Force Base. The city functions under a Home Rule Charter which provides for the financing, construction, and operation of a water supply system. The city's water department operates the water supply and treatment facilities. Grand Forks obtains water from both the Red River of the North and the Red Lake River. The city has obtained the rights to Red Lake River water from the State of Minnesota. Right to Red River of the North water was given by the North Dakota State Water Commission. The city supplies water to the Grand Forks Air Force Base through a contract with the base. The base has participated in the construction of the water treatment plant and owns and maintains the transmission pipeline between the city and the base.

The Grand Forks Air Force Base Environmental Support provides water supply to the base. The agency purchases water from the city of Grand Forks. It operates and maintains the base distribution system and the transmission pipeline between the base and Grand Forks. The agency is responsible only for services to facilities on the base.

Emerado supplies water to users within its corporate boundary. The city has the authority to finance, plan, construct, and operate its water system. The city's water supply is obtained from nearby wells, transported to the city, and distributed.

In summary, Grand Forks and East Grand Forks currently supply water to the immediate urban area. Emerado provides water within its boundaries and rural water associations supply rural users who are located beyond the major population centers. A number of other local and regional agencies have the authority to provide water but are not currently providing them. State and Federal agencies have regulatory functions to ensure safe water is distributed to users.

FUTURE INSTITUTIONAL FRAMEWORK

Grand Forks and East Grand Forks have expressed the willingness and desire to continue supplying water to their customers. Emerado and the three rural water associations also wish to continue providing water. However, each entity has indicated that it would consider a regional approach if cost savings can be shown.

The Stage 2 Water Supply Study indicated that the rural water associations should continue as separate entities rather than become part of a regional system. Emerado would also remain independent unless the Elk Valley aquifer alternative were implemented. In this case, the water transmission pipeline from the well field and treatment facilities would pass near Emerado and an excellent quality water supply would be available to the city. Emerado would continue its responsibility for distributing the water to its customers.

There are several alternative arrangements available for supplying and treating water to Grand Forks and East Grand Forks, including:

1. Separate supply and separate treatment.
2. Regional supply and separate treatment.
3. Regional supply and treatment.

The alternative selected will vary with the water supply alternatives considered. For example, if the Elk Valley aquifer is used, a regional supply and treatment arrangement would probably be used. If the surface water supply is used, all three arrangements could be used.

The institutional arrangements for separate supply and/or treatment would involve a continuation of existing individual agencies' legal authority.

The institutional arrangements required to establish a regional supply and/or treatment system are complicated due to the interstate nature of the area. North Dakota and Minnesota laws must be considered. The institutional analysis included in the Stage 2 Background Information Appendix indicates that there are few formal agreements or arrangements between governmental entities in the GF/EGF urban area. A formal mutual fire aid agreement exists between East Grand Forks, Crookston, Grand Forks, and the Grand Forks Air Force Base. East Grand Forks uses the Grand Forks landfill through a 5-year agreement between the users. Grand Forks and East Grand Forks have interconnected their water distribution systems but no formal agreement has been executed. Grand Forks has obtained a permit from the Minnesota Department of Natural Resources to use Red Lake River water. Grand Forks has also constructed an intake and pipeline in East Grand Forks to transport the Red Lake River water to the Grand Forks water treatment plant.

The North Dakota Century Code 40-34-15 authorizes North Dakota municipalities to cooperate and to enter into contracts with other governmental agencies and municipalities within North Dakota and in other States. Grand Forks is governed under a

Home Rule Charter so it may enter into agreement with other governmental entities within and outside the state of North Dakota. The State 2 Background Information Appendix does not indicate whether East Grand Forks can enter into agreements with other entities within or outside of Minnesota.

Regional water supply and/or treatment will require some type of formal arrangement. Several institutional arrangements have been used for existing intergovernmental agreements. These procedures could be used for future arrangements and include:

1. A formal agreement between entities through which powers are jointly exercised.
2. A contract between entities where one entity sells services to another entity.
3. Formation of a special purpose district set up through State legislation passed by both North Dakota and Minnesota.

Under the formal agreement arrangement, a joint governing board would be established and include members from each entity. The agreement would specify the rules for governing, the area to be served, the terms of the agreement, the services to be provided, and the planning, financing, construction, and operation procedures. An executive director and a staff would carry out the board's policies and operate the facilities. This agreement would probably cover the joint provision of water supply and treatment, while the individual entities would continue to distribute water to their customers.

Under a contract for service arrangement, one entity would be responsible for planning, financing, constructing, and operating water supply and/or treatment facilities. Other entities would contract with the lead entity for the water supply and/or treatment services. Services would be received for an established fee and under specified conditions contained in the contract.

Under the special district arrangement, a special charter would be needed. The legal authority for this district would be established by the legislatures of North Dakota and Minnesota. The special charter would specify the authority, responsibilities, and duties of the two-State district. The charter would include provision of the boundaries, the governing body, the methods of financing and assessing charges, and the authority to acquire, plan, construct, operate, and maintain facilities. The district would be responsible for water supply and treatment, while the individual entities would continue to distribute water to their customers.

Under each arrangement, attention must be given to include the existing contract between the Grand Forks Air Force Base and Grand Forks. Consideration of the existing water right which each entity has received through the State permit systems is necessary. Legislative approval could be used to allocate water rights to a regional water supply entity which supplies water to the urban area.

The institutional analysis included in the Stage 2 Background Information Appendix stated:

> Because the two major municipalities involved are located in different States, cooperation in water resources management can be arranged more satisfactorily by formal agreement than by contract or by formation of a district.

Through a formal agreement, all entities share in the management and decision-making functions. Each entity is therefore able to protect its interests on a continuous basis. Under a contract arrangement, the terms are fixed until such time as the contract is renegotiated. A special district would be difficult to set up because initial capital and manpower requirements and legislative acts in both States would be required. The initial costs

would be associated organization costs, purchase of existing facilities, and construction of new facilities.

In summary, any separate system would continue to be managed through existing institutional arrangements. Regional water supply and/or treatment systems should be organized through formal agreements between the participating entities.

COMPREHENSIVE WATER SUPPLY ALTERNATIVES

GENERAL

This section summarizes the overall comprehensive water supply alternatives that can satisfy the projected water demands for the Grand Forks-East Grand Forks urban area through year 2030. Each comprehensive alternative is a total system that pulls together the individual components of water supply, raw water storage, water transmission, water treatment, and management practices.

EXISTING BASE CONDITIONS

The Grand Forks-East Grand Forks urban area is a major service, educational, and agricultural product processing center serving northeast North Dakota and northwest Minnesota. Agricultural production near the area has become more centralized and has grown significantly. The agricultural processing industry has also grown, creating more jobs. The jobs attract more persons who demand more services. Unlike the rural areas of North Dakota and Minnesota, the Grand Forks-East Grand Forks urban area is growing rapidly. The urban population, agricultural processing industries, and service industries are projected to grow and expand.[1,2,8]

Without an adequate water supply, the urban area cannot continue its healthy growth. Economic and industrial growth will be hindered. A no-growth situation may occur or population growth may continue without jobs so the socioeconomic character of the area may decline. As a minimum, the area may be forced to suffer through periods of water shortage.

Grand Forks and East Grand Forks obtain their water supply from the Red River of the North and the Red Lake River. Water is withdrawn, treated, and distributed to the area users. The specific water system needs, problems, and adequacies were discussed in previous sections of this report. In general, water

treatment facilities must be expanded now at Grand Forks and in the future at Grand Forks and East Grand Forks as growth exceeds capabilities. Measures must be taken to ensure the reliability of the water supply sources including replacement of the low-head dams on the two rivers and continued maintenance of all water supply and treatment facilities. Facilities must be replaced as they exceed their service life. Reliance on only one transmission main serving the Grand Forks Air Force Base would leave the base without a water supply source during a major main break.

Concern over recurrence of the 1930's type drought has been expressed by local officials and was identified as one of the major water supply problems facing the urban area. However, detailed low-flow studies indicate that the water shortages of the 1930's should not recur within any reasonable design period. The 1930's drought was an extreme event that is projected to have a recurrence frequency less than once in 200 years. Also Corps-operated reservoirs have been improved and constructed since the 1930's drought. These reservoirs were built in the early 1950's and are operated to augment low flows. Therefore, maintaining existing water supply and treatment systems is more important than developing alternative supply sources and/or supply augmentation.

COST ANALYSIS

The economic analysis of alternatives is conducted for the 50-year study period ending in year 2030. The analysis includes construction costs, replacement costs, operation and maintenance costs, and equivalent annual costs. Except for major plant refurbishing, the replacement costs are not identified separately, but are included in the average service (design) life of the facilities. The average service lives are assumed to be 25 years for water treatment plants and 50 years for transmission mains, pump stations, off-channel storage reservoirs, and low-head dams.

Major plant refurbishing includes replacement of treatment plant equipment which extends the useful life of the existing plants. Refurbishing matches the service life and design capacity of the plants and establishes a reasonable replacement schedule.

The economic analysis identifies the relative cost effectiveness of each alternative. Those alternatives which have a lower equivalent annual cost are more cost effective.

All costs are based on January 1979 price levels and reflect costs experienced in the Grand Forks and East Grand Forks area. An interest rate of 6 7/8 percent per year is used to convert costs to equivalent annual costs for the 50-year study period. The interest rate is based on the Water Resources Council regulation and is effective from October 1978 to October 1979. The Engineering News Record Construction Cost Index for 18 January 1979 was 2,870.

Construction and operation and maintenance costs are given on the cost curves presented in the previous sections. Construction costs are based on maximum day demands, while operation and maintenance costs are based on average day demands. Total capital costs include construction costs plus 25 percent of construction costs for administration, engineering, and legal expenses and contingencies, plus 8 percent of construction costs for interest during construction, plus land costs. Transmission mains are assumed to be routed along existing easements and rights-of-way, so no additional costs will be incurred.

Future construction cost, operation and maintenance costs, and salvage values are converted to equivalent present worth amounts, then to equivalent annual costs. Salvage values for facilities which have service lives remaining at the end of the study period are estimated using straight-line depreciation. Salvage value of land is the same as the initial cost of $7,000 per acre. The land cost of $7,000 per acre is used because facilities will be constructed on prime agricultural land and/or prime development land. The Grand Forks County Planning Commission and the Polk County Assessor have indicated that land will be difficult to obtain.

RANGE OF ALTERNATIVES

Each comprehensive alternative has four components. Various combinations of the four components produce a range of alternatives. An "outline form" numbering system is used to identify each component. The four part number identifies each comprehensive alternative. The components and the numbering system are as follows:

Water Supply Sources -

I. Surface water from the Red River of the North and the Red Lake River.

II. Garrison Diversion water to supplement the Red River of the North flow.

III. Groundwater from the Elk Valley aquifer.

Water Quality Standards -

A. Interim primary drinking water standards.

B. Proposed advanced drinking water standards.

Water Conservation Practices -

1. Without water conservation practices.
2. With water conservation practices.

Separate or Combined Systems -

a. Separate supply and treatment.

b. Combined supply and treatment in year 2005.

c. Combined supply and treatment in year 1990.

WATER DEMANDS

The Grand Forks and East Grand Forks water demands which must be satisfied are listed below for convenient reference. The alternative water supply and treatment systems must be able to satisfy these water demands. Separate systems must satisfy the individual community demands while combined systems must satisfy the total demands. The projected water demands are as follows:

	1980	1990	2000	2010	2020	2030
Grand Forks						
Ave. Day (mgd)	7.71	8.59	9.64	10.83	12.17	13.67
Max. Day (mgd)	13.26	14.77	16.58	18.63	20.93	23.51
East Grand Forks						
Ave. Day (mgd)	1.50	1.71	1.95	2.22	2.52	2.86
Max. Day (mgd)	2.79	3.18	3.63	4.13	4.69	5.32
Total						
Ave. Day (mgd)	9.21	10.30	11.35	13.05	14.69	16.53
Max. Day (mgd)	16.05	17.95	20.21	22.76	25.62	28.83

The water demands for self-supplied industries are listed earlier in this report. The self-supplied industries and rural water districts will continue to supply their own water demands.

ALTERNATIVE I-A-1-a

This alternative involves the continuation of existing water supply, treatment, and management systems. Each community will continue to own and operate its own water system. Grand Forks will continue serving the Grand Forks Air Force Base. Self-supplied industries and rural water districts in the study area will continue to supply their needs separately. No changes to existing management and institutional arrangements are required.

Figure 31 shows the conceptual plan for this alternative. The major components of this comprehensive alternative include:

I. Surface water from the Red River of the North and the Red Lake River.

A. Interim primary drinking water standards.

1. Without water conservation practices.

a. Separate supply and treatment.

Table 26 summarizes the proposed schedule of improvements, their costs, and the design criteria. The existing Grand Forks maximum day water demands exceed the 12-mgd treatment plant capacity, so treatment plant expansion is needed immediately.

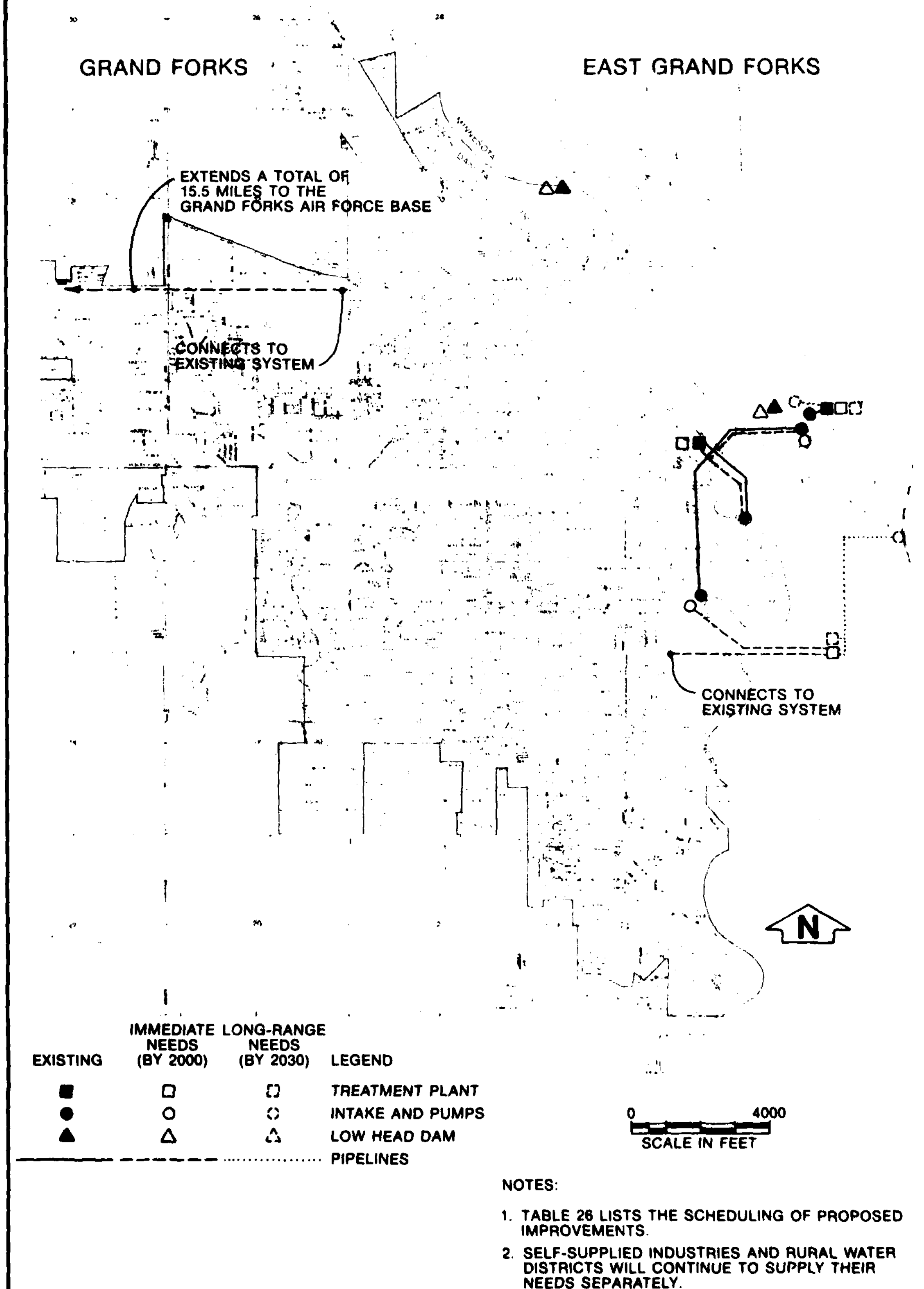


Figure 31 - Alternative I-A-1-a Conceptual Plan

A second transmission line between Grand Forks and the Grand Forks Air Force Base is included to increase the reliability of the base supply. Other facility improvements are recommended as the service life and/or design capacity of each element is exceeded. Service lives are based on the initial and/or average construction date of each element. The service lives of some facilities are extended by refurbishing. The costs for refurbishing include replacement of major equipment which exceed its service lives sooner than concrete structures. The refurbished facilities are then replaced on a more uniform base with other facilities.

ALTERNATIVE I-A-1-b

This alternative involves both continuation of existing and eventual combination of water supply, treatment and management systems. Each community will continue to own and operate its own water system through year 2005. In year 2005, a regional water supply treatment system will replace the existing systems. The regional system will be organized through a formal agreement between the participating entities. The formal agreement would specify the management, decision-making, and financing arrangements. Grand Forks will continue serving the Grand Forks Air Force Base. Self-supplied industries and rural water districts in the study area will continue to supply their needs separately. Although a regional system is not proposed until year 2005, management of the water systems could be combined before year 2005 if the communities desired.

Table 26 - Alternative I-A-1-a proposed improvements and costs

Year	Item	Cost ($)	Notes(1)
Grand Forks			
1980	Capital Costs	9,670,000	New 6-mgd treatment plant and land.
		3,820,000	New supply at 6 mgd pumping and 24 mgd structural.
1980	O&M Supply	28,000	For existing 7.7-mgd and new 0-mgd flow. Increases linearly to 2005 value.
1980	O&M Treatment	1,360,000	For existing 7.7-mgd and new 0-mgd flow. Increases linearly to 2005 value.
1985	Capital Cost	170,000	Refurbish GF #3 supply.
1985	O&M Storage	20,000	Maintain RRN low-head dam.
1990	Capital Costs	2,510,000	Replace RRN low-head dam.
		80,000	Refurbish GF #1 supply.
		4,970,000	Refurbish existing 12-mgd treatment plant.
1990	O&M Storage	20,000	Maintain RRN low-head dam in eight 5-year intervals to 2030.
2005	O&M Supply	36,000	Existing 7.7-mgd and new 2.6-mgd flow.
2005	O&M Treatment	2,040,000	Existing 7.7-mgd and new 2.6-mgd flow.
2005	Abandon Facilities	0	GF #1, 2, and 3 supply and existing 12-mgd treatment plant. No salvage value.
2005	Capital Costs	131,000	Expand supply to 24 mgd (pumping only).
		25,900,000	New 24-mgd treatment plant.
2005	O&M Supply	30,000	For 10.3-mgd flow. Increases linearly to 2030 value.
2005	O&M Treatment	1,840,000	For 10.3-mgd flow. Increases linearly to 2030 value.
2030	O&M Supply	38,000	For 13.7-mgd flow.
2030	O&M Treatment	2,350,000	For 13.7-mgd flow.
2030	Salvage	643,000	RRN low-head dam and land.
East Grand Forks			
1980	O&M Supply	5,000	For existing 1.5-mgd flow. Increases linearly to 2005 value.
1980	O&M Treatment	427,000	For existing 1.5-mgd flow. Increases linearly to 2005 value.
1990	Capital Cost	3,080,000	Refurbish existing 4-mgd treatment plant.
2005	Capital Cost	269,000	New 7-mgd supply.
		9,200,000	New 6-mgd treatment plant.
2005	O&M Supply	6,000	For 2.1-mgd flow. Increases linearly to 2030 value.
2005	O&M Treatment	514,000	For 2.1-mgd flow. Increases linearly to 2030 value.
2030	O&M Supply	8,000	For 2.9-mgd flow.
2030	O&M Treatment	630,000	For 2.9-mgd flow.
2030	Salvage	135,000	Supply.
Shared Facilities			
1985	O&M Storage	20,000	Maintain RLR low-head dam.
1990	Capital Cost	3,140,000	Replace RLR low-head dam.
1990	O&M Salvage	20,000	Maintain RLR low-head dam in eight 5-year intervals to 2030.
2030	Salvage	628,000	RLR low-head dam.
Grand Forks Air Force Base			
1980	Capital Cost	6,290,000	For supply, 15.5 miles of 15" pipe from Grand Forks to base.
1980	O&M Supply	19,000	For existing 16" and new 15" pipe. Uniform to 2030.
Equivalent Annual Cost		4,620,000	

Notes: (1) Components of supply are intake structures and water transmission lines.
RRN - Red River of the North
RLR - Red Lake River
Unless otherwise stated, O&M costs are assumed to be applied annually.

Source: Stanley Consultants, Inc.

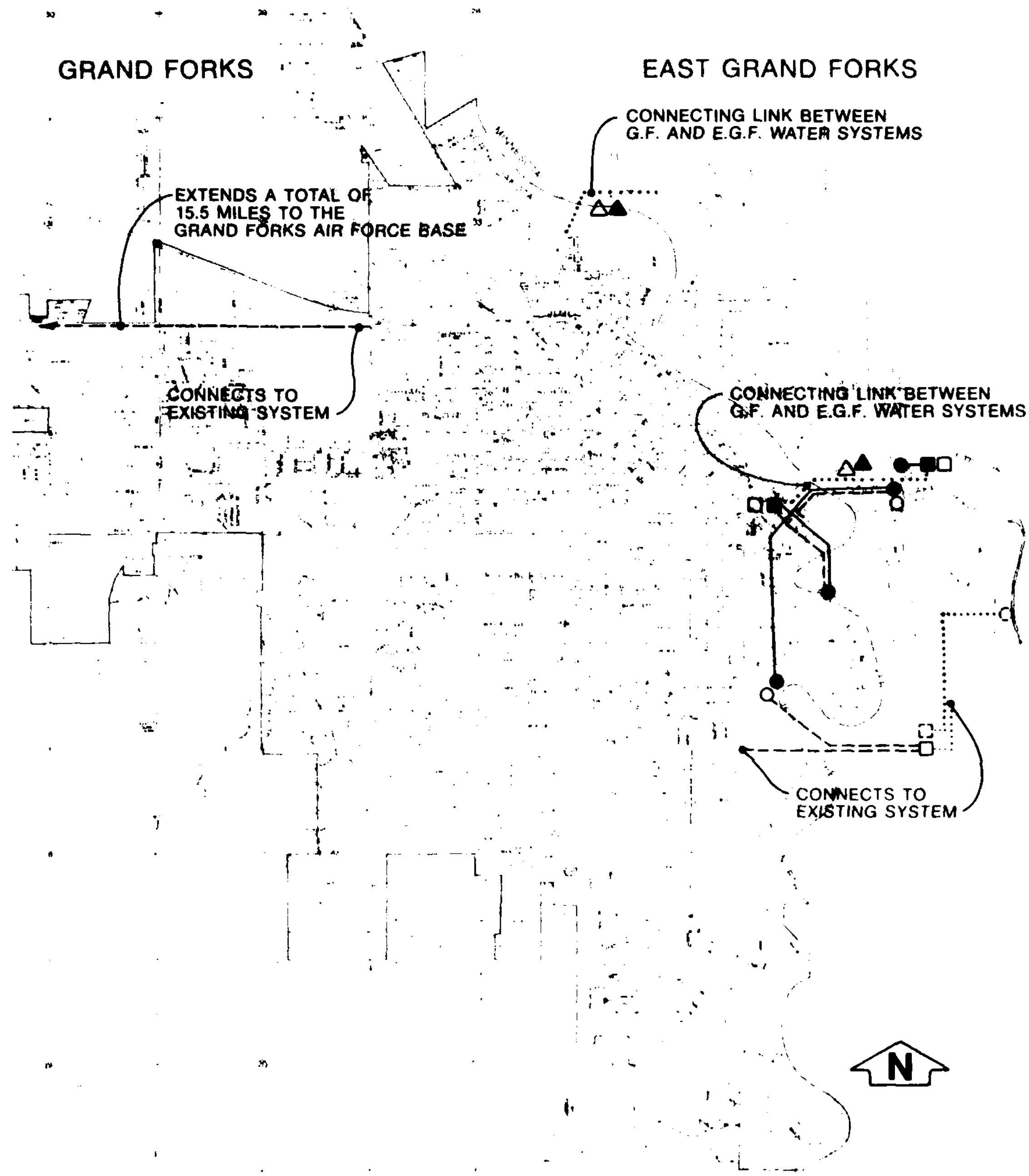
Figure 32 presents the conceptual plan for this alternative. The major components of this comprehensive alternative include:

I. Surface water from the Red River of the North and the Red Lake River.

A. Interim primary drinking water standards.

1. Without water conservation practices.

b. Combined supply and treatment as facilities exceed their service lives.



EXISTING	IMMEDIATE NEEDS (BY 2000)	LONG-RANGE NEEDS (BY 2030)	LEGEND
■	□	⬚	TREATMENT PLANT
●	○	◌	INTAKE AND PUMPS
▲	△	△	LOW HEAD DAM
————	– – – –	....	PIPELINES

0 4000
SCALE IN FEET

NOTES:

1. TABLE 27 LISTS THE SCHEDULING OF PROPOSED IMPROVEMENTS.
2. SELF-SUPPLIED INDUSTRIES AND RURAL WATER DISTRICTS WILL CONTINUE TO SUPPLY THEIR NEEDS SEPARATELY.

Figure 32 - Alternative I-A-1-b Conceptual Plan

Table 27 summarizes the proposed schedule of improvements, their costs, and the design criteria. A water treatment plant expansion is needed immediately for Grand Forks. The Grand Forks 12-mgd and East Grand Forks 4-mgd water treatment plants must be refurbished in 1990 to extend their service lives to year 2005. In year 2005, a regional water treatment plant will be built to serve both communities. Cost savings will be realized through economies of scale associated with one larger capacity plant versus two smaller plants for both construction and operation and maintenance. East Grand Forks would be served by two river crossing links which will connect the large diameter piping in the two cities.

Table 27 - Alternative I-A-1-b proposed improvements and costs

Year	Item	Cost ($)	Notes(1)
Grand Forks			
1980	O&M Supply	23,000	For existing 7.7-mgd flow. Uniform to 2005.
1980	O&M Treatment	1,360,000	For existing 7.7-mgd flow. Uniform to 2005.
1985	Capital Cost	170,000	Refurbish GF #3 supply.
1990	Capital Cost	80,000	Refurbish GF #1 supply.
		4,970,000	Refurbish existing 12-mgd treatment plant.
2005	Abandon Facilities	0	GF #1, 2, and 3 supply and existing 12-mgd treatment plant. No salvage value.
East Grand Forks			
1980	O&M Supply	5,000	For existing 1.5-mgd flow. Increases linearly to 2005 value.
1980	O&M Treatment	427,000	For existing 1.5-mgd flow. Increases linearly to 2005 value.
1990	Capital Cost	3,120,000	Refurbish existing 4-mgd treatment plant.
2005	O&M Supply	6,000	For 2.1-mgd flow.
2005	O&M Treatment	514,000	For 2.1-mgd flow.
2005	Abandon Facilities	0	Supply and existing 4-mgd treatment plant. No salvage value.
Combined Facilities			
1980	Capital Cost	9,670,000	New 6-mgd treatment plant and land.
		3,880,000	New supply for 6-mgd pumping and 20-mgd structural.
1980	O&M Supply	5,000	For 0-mgd flow. Increases linearly to 2005 value.
1980	O&M Treatment	0	For 0-mgd flow. Increases linearly to 2005 value.
1985	O&M Storage	20,000	Maintain RRN low-head dam.
		20,000	Maintain RLR low-head dam.
1990	Capital Cost	2,510,000	Replace RRN low-head dam.
		3,140,000	Replace RLR low-head dam.
1990	O&M Storage	20,000	Maintain RRN low-head dam in eight 5-year intervals to 2030.
		20,000	Maintain RLR low-head dam in eight 5-year intervals to 2030.
2005	O&M Supply	12,000	For 2.6-mgd flow.
2005	O&M Treatment	674,000	For 2.6-mgd flow.
2005	Relocation of GF/EGF Supply/Treatment to new site		
2005	Capital Cost	1,160,000	Expand supply to 30 mgd (pumping only).
		31,300,000	New 30-mgd treatment plant.
2005	O&M Supply	37,000	For 12.4-mgd flow. Increases linearly to 2030 value.
2005	O&M Treatment	2,150,000	For 12.4-mgd flow. Increases linearly to 2030 value.
2030	O&M Supply	46,000	For 16.7-mgd flow.
2030	O&M Treatment	2,800,000	For 16.7-mgd flow.
2030	Salvage	1,770,000	Low-head dams, supply, land.
Grand Forks Air Force Base			
1980	Capital Cost	6,290,000	For supply, 15.5 miles of 15" pipe from GF to base.
1980	O&M Supply	19,000	Existing 16" and new 15" pipe Uniform 402030.
Equivalent Annual Cost		4,560,000	

Notes: (1) Components of supply are intake structures and water transmission lines.
RRN - Red River of the North
RLR - Red Lake River
Unless otherwise stated, O&M costs are assumed to be applied annually.

Source: Stanley Consultants, Inc.

ALTERNATIVE I-A-1-c

This alternative involves combining the water supply, treatment, and management system functions into a regional system in 1990. The service lives of both the Grand Forks and East Grand Forks water treatment plants will be exceeded in year 1990, so regionalization should occur in 1990. The existing water supply and treatment facilities will be abandoned when the regional facilities are constructed. The regional system will be organized through a formal agreement between the participating entities. The formal agreement will specify the management, decision-making, and financing arrangements. Grand Forks will continue serving the Grand Forks Air Force Base. Self-supplied industries and rural water districts in the study area will continue to supply their needs separately.

Figure 33 presents the conceptual plan for this alternative. The major components of this comprehensive alternative include:

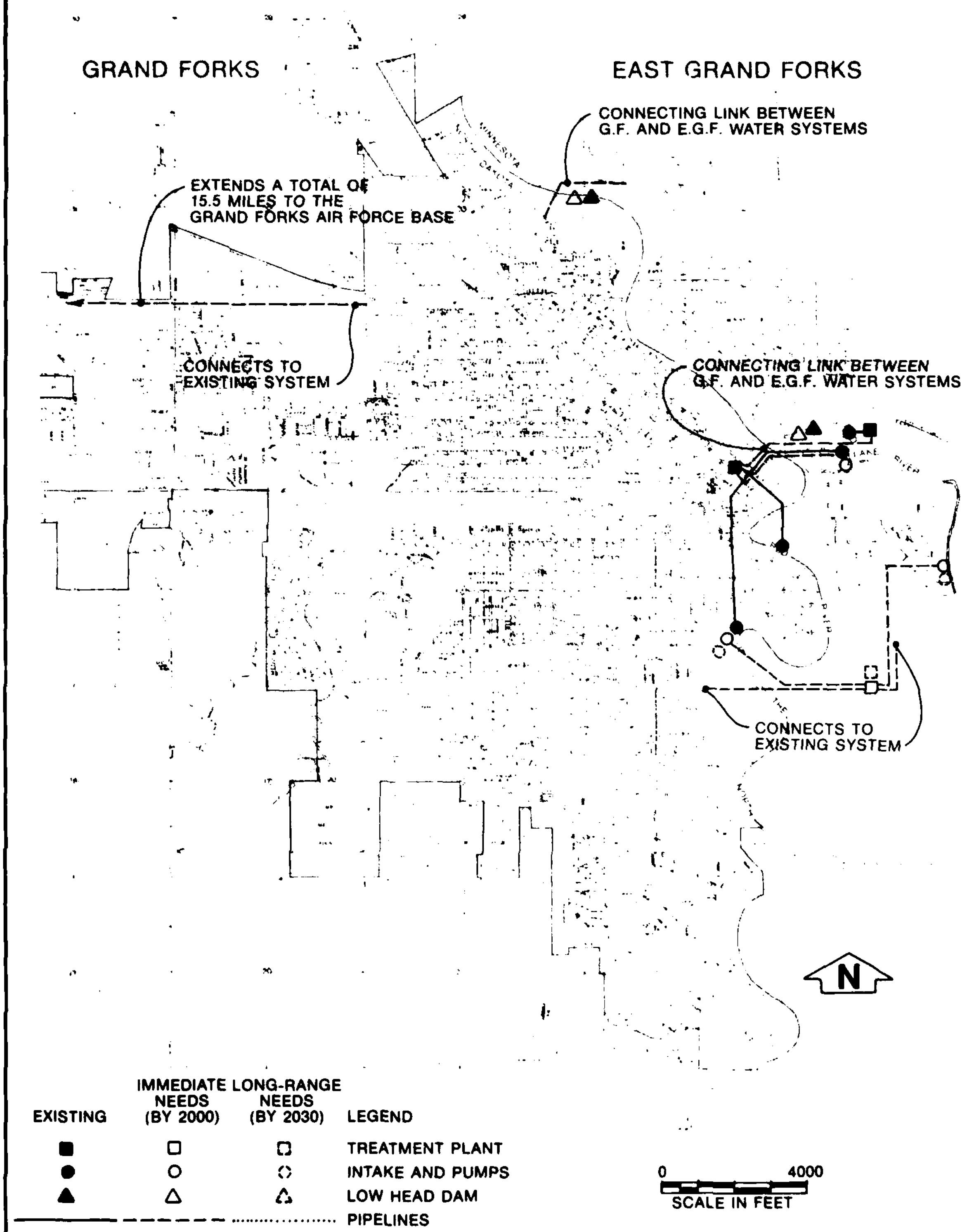
I. Surface water from the Red River of the North and the Red Lake River.

A. Interim primary drinking water standards.

1. Without water conservation practices.

c. Combined supply and treatment as soon as possible.

Table 28 summarizes the proposed schedule of improvements, their costs, and the design criteria. A water treatment plant expansion is needed immediately for Grand Forks. Instead of refurbishing the Grand Forks 12-mgd and East Grand Forks 4-mgd water treatment plants, these plants will be abandoned in 1990. A regional water supply and treatment system will be constructed to serve both cities. Cost savings will be realized through economies of scale associated with one larger capacity system. Past experience has shown that construction and operation and maintenance costs are reduced because an increase in the diameter or width of a basin significantly increases its capacity but adds only a slight increase in capital costs. Also, there are efficiencies in operating a larger capacity facility because many of the same functions must be performed in each plant regardless of its size.



NOTES:

1. TABLE 28 LISTS THE SCHEDULING OF PROPOSED IMPROVEMENTS.
2. SELF-SUPPLIED INDUSTRIES AND RURAL WATER DISTRICTS WILL CONTINUE TO SUPPLY THEIR NEEDS SEPARATELY.

Figure 33 - Alternative I-A-1-c Conceptual Plan

Table 28 - Alternative I-A-1-c proposed improvements and costs

Year	Item	Cost ($)	Notes[1]
Grand Forks			
1980	O&M Supply	23,000	For existing 7.7-mgd flow. Uniform to 1990.
1980	O&M Treatment	1,360,000	For existing 7.7-mgd flow. Uniform to 1990.
1985	Capital Cost	170,000	Refurbish GF #3 supply.
1990	Abandon Facilities	0	GF #1, 2, and 3 supply and existing 12-mgd treatment plant. No salvage value.
East Grand Forks			
1980	O&M Supply	5,000	For existing 1.5-mgd flow. Increases linearly to 1990 value.
1980	O&M Treatment	427,000	For existing 1.5-mgd flow. Increases linearly to 1990 value.
1990	O&M Supply	6,000	For 1.7-mgd flow.
1990	O&M Treatment	459,000	For 1.7-mgd flow.
1990	Abandon Facilities	0	Supply and existing 4-mgd treatment plant. No salvage value.
Combined Facilities			
1980	Capital Cost	9,670,000	New 6-mgd treatment plant and land.
		1,580,000	Supply for 6-mgd pumping (RRN).
1980	O&M Supply	2,000	For 0-mgd flow. Increases linearly to 1990 value.
1980	O&M Treatment	0	For 0-mgd flow. Increases linearly to 1990 value.
1985	O&M Storage	20,000	Maintain RRN low-head dam.
		20,000	Maintain RLR low-head dam.
1990	O&M Supply	5,000	For 1.0-mgd flow.
1990	O&M Treatment	270,000	For 1.0-mgd flow.
1990	Capital Cost	2,510,000	Replace RRN low-head dam.
		3,140,000	Replace RLR low-head dam.
		2,240,000	Expand supply to 30 mgd (RRN and RLR).
		26,000,000	Replace GF/EGF treatment plants.
1990	O&M Storage	20,000	Maintain RRN low-head dam in eight 5-year intervals to 2030.
		20,000	Maintain RLR low-head dam in eight 5-year intervals to 2030.
1990	O&M Supply	30,000	For 10.3-mgd flow. Increases linearly to 2030 value.
1990	O&M Treatment	1,840,000	For 10.3-mgd flow. Increases linearly to 2015 value.
2005	Capital Cost	3,620,000	Refurbish original 6-mgd treatment cell.
2015	Capital Cost	33,700,00	Replace all treatment to 33-mgd capacity.
2015	O&M Treatment	2,400,000	For 14-mgd flow. Increases linearly to 2030 value.
2030	O&M Supply	45,000	For 16.7-mgd flow.
2030	O&M Treatment	2,800,000	For 16.7-mgd flow.
2030	Salvage	15,000,000	Low-head dams, supply, treatment, land.
Grand Forks Air Force Base			
1980	Capital Cost	6,290,000	For supply 15.5 miles of 15" pipe from GF to base.
1980	O&M Supply	19,000	For supply existing 16" and new 15" pipe. Uniform to 2030.
Equivalent Annual Cost		4,830,000	

Notes: (1) Components of supply are intake structures and water transmission lines.
RRN - Red River of the North
RLR - Red Lake River
Unless otherwise stated, O&M costs are assumed to be applied annually.

Source: Stanley Consultants, Inc.

ALTERNATIVE I-A-2-a

This alternative is the same as alternative I-A-1-a except water conservation practices are implemented. These practices reduce the maximum day water demand by about 10 percent and average day demands by about 8 percent, so smaller capacity facilities are required.

Table 29 summarizes the proposed schedule of improvements, their costs, and the design criteria for this alternative. The conceptual plan is the same as shown on figure 31.

ALTERNATIVE I-A-2-b

This alternative is the same as alternative I-A-1-b except water conservation practices are implemented. These practices reduce the maximum day water demand by about 10 percent and average day demands by about 8 percent, so smaller capacity facilities are required.

Table 30 summarizes the proposed schedule of improvements, their costs, and the design criteria for this alternative. The conceptual plan is the same as shown on figure 32.

ALTERNATIVE I-A-2-c

This alternative is the same as alternative I-A-1-c except water conservation practices are implemented. These practices reduce the maximum day water demand by about 10 percent and average day demands by about 8 percent, so smaller capacity facilities are required.

Table 31 summarizes the proposed schedule of improvements, their costs, and the design criteria for this alternative. The conceptual plan is the same as shown on figure 33.

ALTERNATIVE I-B-1-a

This alternative adds a granular activated carbon process to all water treatment plants needed in alternative I-A-1-a. This process is capable of satisfying the proposed advanced drinking water standards.

Table 32 summarizes the proposed schedule of improvements, their costs, and the design criteria for this alternative. The conceptual plan is the same as shown on figure 31.

Table 29 - Alternative I-A-2-a proposed improvements and costs

Year	Item	Cost ($)	Notes(1)
Grand Forks			
1980	Capital Costs	7,650,000	New 4-mgd treatment plant and land.
		1,562,000	New supply at 4-mgd pumping (RRN).
1980	O&M Supply	24,000	For existing 7.1-mgd and new 0-mgd flow. Increases linearly to 2005 value.
1980	O&M Treatment	1,280,000	For existing 7.1-mgd and new 0-mgd flow. Increases linearly to 2005 value.
1985	Capital Costs	170,000	Refurbish GF #3 supply.
1985	O&M Storage	20,000	Maintain RRN low-head dam.
1990	Capital Costs	2,510,000	Replace RRN low-head dam.
		80,000	Refurbish GF #1 supply.
		5,050,000	Refurbish existing 12-mgd treatment plant.
1990	O&M Storage	20,000	Maintain RRN low-head dam in eight 5-year intervals to 2030.
2005	O&M Supply	30,000	Existing 7.1-mgd and new 2.3-mgd flow.
2005	O&M Treatment	1,870,000	Existing 7.1-mgd and new 2.3-mgd flow.
2005	Abandon Facilities	0	GF #1, 2, and 3 supply and existing 12-mgd treatment plant. No salvage value.
2005	Capital Costs	944,000	Expand supply to 22 mgd (RRN and RLR).
		24,200,000	New 22-mgd treatment plant.
2005	O&M Supply	26,000	For 9.4-mgd flow. Increases linearly to 2030 value.
2005	O&M Treatment	1,720,000	For 9.4-mgd flow. Increases linearly to 2030 value.
2030	O&M Supply	34,000	For 12.6-mgd flow.
2030	O&M Treatment	2,200,000	For 12.6-mgd flow.
2030	Salvage	1,050,000	RRN low-head dam and land.
East Grand Forks			
1980	O&M Supply	4,000	For existing 1.4-mgd flow. Increases linearly to 2005 value.
1980	O&M Treatment	409,000	For existing 1.4-mgd flow. Increases linearly to 2005 value.
1990	Capital Costs	3,000,000	Refurbish existing 4-mgd treatment plant.
2005	Capital Costs	264,000	New 7-mgd supply.
		8,250,000	New 5-mgd treatment plant
2005	O&M Supply	6,000	For 1.9-mgd flow. Increases linearly to 2030 value.
2005	O&M Treatment	485,000	For 1.9-mgd flow. Increases linearly to 2030 value.
2030	O&M Supply	8,000	For 2.6-mgd flow.
2030	O&M Treatment	588,000	For 2.6-mgd flow.
2030	Salvage	103,000	Supply.
Shared Facilities			
1985	O&M Storage	20,000	Maintain RLR low-head dam.
1990	Capital Costs	3,140,000	Replace RLR low-head dam.
1990	O&M Storage	20,000	Maintain RLR low-head dam in eight 5-year intervals to 2030.
2030	Salvage	627,000	RLR low-head dam.
Grand Forks Air Force Base			
1980	Capital Costs	6,290,000	For supply, 15.5 miles of 15" pipe from Grand Forks to base.
1980	O&M Supply	19,000	Existing 16" and new 15" pipe. Uniform to 2030.
Equivalent Annual Cost		4,170,000	

Notes: (1) Components of supply are intake structures and water transmission lines.
RRN - Red River of the North
RLR - Red Lake River
Unless otherwise stated, O&M costs are assumed to be applied annually.

Source: Stanley Consultants, Inc.

Table 30 - Alternative I-A-2-b proposed improvements and costs

Year	Item	Cost ($)	Notes(1)
Grand Forks			
1980	O&M Supply	22,000	For existing 7.1-mgd flow. Uniform to 2005.
1980	O&M Treatment	1,280,000	For existing 7.1-mgd flow. Uniform to 2005.
1985	Capital Costs	170,000	Refurbish GF #3 supply.
1990	Capital Costs	80,000	Refurbish GF #1 supply.
		5,050,000	Refurbish existing 12-mgd treatment plant.
2005	Abandon Facilities	0	GF #1, 2, and 3 supply and existing 12-mgd treatment plant. No salvage value.
East Grand Forks			
1980	O&M Supply	4,000	For existing 1.4-mgd flow. Increases linearly to 2005 value.
1980	O&M Treatment	409,000	For existing 1.4-mgd flow. Increases linearly to 2005 value.
1990	Capital Costs	3,000,000	Refurbish existing 4-mgd treatment plant.
2005	O&M Supply	6,000	For 1.9-mgd flow.
2005	O&M Treatment	485,000	For 1.9-mgd flow.
2005	Abandon Facilities	0	Supply and existing 4-mgd treatment plant. No salvage value.
Combined Facilities			
1980	Capital Costs	7,650,000	New 4-mgd treatment plant and land.
		1,552,000	Supply for 4-mgd pumping (RRN).
1980	O&M Supply	2,000	For 0-mgd flow. Increases linearly to 2005 value.
1980	O&M Treatment	0	For 0-mgd flow. Increases linearly to 2005 value.
1985	O&M Storage	20,000	Maintain RRN low-head dam.
		20,000	Maintain RLR low-head dam.
1990	Capital Costs	2,510,000	Replace RRN low-head dam.
		3,140,000	Replace RLR low-head dam.
1990	O&M Storage	20,000	Maintain RRN low-head dam in eight 5-year intervals to 2030.
		20,000	Maintain RLR low-head dam in eight 5-year intervals to 2030.
2005	O&M Supply	9,000	For 2.3-mgd flow.
2005	O&M Treatment	584,000	For 2.3-mgd flow.
2005	Relocation of GF/EGF Supply/Treatment to New Site		
2005	Capital Cost	2,024,000	Expand supply to 26 mgd (RRN and RLR).
		27,900,000	New 26-mgd treatment plant.
2005	O&M Supply	32,000	For 11.3-mgd flow. Increases linearly to 2030 value.
2005	O&M Treatment	2,000,000	For 11.3-mgd flow. Increases linearly to 2030 value.
2030	O&M Supply	42,000	For 15.2-mgd flow.
2030	O&M Treatment	2,550,000	For 15.2-mgd flow.
2030	Salvage	2,130,000	Low-head dams, supply, land.
Grand Forks Air Force Base			
1980	Capital Costs	6,290,000	For supply, 15.5 miles of 15" pipe from GF to base.
1980	O&M Supply	19,000	Existing 16" and new 15" pipe. Uniform to 2030.
Equivalent Annual Cost		4,070,000	

Notes: (1) Components of supply are intake structures and water transmission lines.
RRN - Red River of the North
RLR - Red Lake River
Unless otherwise stated, O&M costs are assumed to be applied annually.

Source: Stanley Consultants, Inc.

Table 31 - Alternative I-A-2-c proposed improvements and costs

Year	Item	Cost ($)	Notes(1)
Grand Forks			
1980	O&M Supply	22,000	For existing 7.1-mgd flow. Uniform to 1990.
1980	O&M Treatment	1,280,000	For existing 7.1-mgd flow. Uniform to 1990.
1985	Capital Costs	170,000	Refurbish GF #3 supply.
1990	Abandon Facilities	0	GF #1, 2, and 3 supply and existing 12-mgd treatment plant. No salvage value.
East Grand Forks			
1980	O&M Supply	4,000	For existing 1.4-mgd flow. Increases linearly to 1990 value.
1980	O&M Treatment	409,000	For existing 1.4-mgd flow. Increases linearly to 1990 value.
1990	O&M Supply	6,000	For 1.6-mgd flow.
1990	O&M Treatment	444,000	For 1.6-mgd flow.
1990	Abandon Facilities	0	Supply and existing 4-mgd treatment plant. No salvage value.
Combined Facilities			
1980	Capital Costs	7,650,000	New 4-mgd treatment plant and land.
		1,552,000	Supply for 4-mgd pumping (RRN).
1980	O&M Supply	2,000	For 0-mgd flow. Increases linearly to 1990 value.
1980	O&M Treatment	0	For 0-mgd flow. Increases linearly to 1990 value.
1985	O&M Storage	20,000	Maintain RRN low-head dam.
		20,000	Maintain RLR low-head dam.
1990	O&M Supply	4,000	For 0.8-mgd flow.
1990	O&M Treatment	330,000	For 0.8-mgd flow.
1990	Capital Costs	2,510,000	Replace RRN low-head dam.
		3,130,000	Replace RLR low-head dam.
		2,024,000	Expand supply to 26 mgd (RRN and RLR).
		20,700,000	Replace GF/EGF treatment plants. Capacity 18 mgd.
1990	O&M Storage	20,000	Maintain RRN low-head dam in eight 5-year intervals to 2030.
		20,000	Maintain RLR low-head dam in eight 5-year intervals to 2030.
1990	O&M Supply	36,000	For 9.5-mgd flow. Increases linearly to 2030 value.
1990	O&M Treatment	1,730,000	For 9.5-mgd flow. Increases linearly to 2015 value.
2005	Capital Costs	3,610,000	Refurbish original 4-mgd treatment cell.
2015	Capital Costs	29,300,000	Replace all treatment to 28-mgd capacity.
2015	O&M Treatment	2,270,000	For 12.7-mgd flow. Increases linearly to 2030 value.
2030	O&M Supply	42,000	For 15.2-mgd flow.
2030	O&M Treatment	2,550,000	For 15.2-mgd flow.
2030	Salvage	13,350,000	Low-head dams, supply, treatment, land.
Grand Forks Air Force Base			
1980	Capital Costs	6,290,000	For supply 15.5 miles of 15" pipe from GF to base.
1980	O&M Supply	19,000	For supply existing 16" and new 15" pipe. Uniform to 2030.
Equivalent Annual Cost		4,330,000	

Notes: (1) Components of supply are intake structures and water transmission lines.
RRN - Red River of the North
RLR - Red Lake River
Unless otherwise stated, O&M costs are assumed to be applied annually.

Source: Stanley Consultants, Inc.

Table 32 - Alternative I-B-1-a proposed improvements and costs

Year	Item	Cost ($)	Notes[1]
Grand Forks			
1980	Capital Costs	12,700,000	New 6-mgd treatment plant and land.
		1,552,000	Supply at 6-mgd pumping (RRN).
1980	O&M Supply	25,000	For existing 7.7-mgd and new 0-mgd flow. Increases linearly to 2005 value.
1980	O&M Treatment	1,560,000	For existing 7.7-mgd and new 0-mgd flow. Increases linearly to 2005 value.
1985	Capital Costs	170,000	Refurbish CF #3 supply.
1985	O&M Storage	20,000	Maintain RRN low-head dam.
1990	Capital Costs	2,510,000	Replace RRN low-head dam.
		80,000	Refurbish CF #1 supply.
		6,510,000	Refurbish existing 12-mgd treatment plant.
1990	O&M Storage	20,000	Maintain RRN low-head dam in eight 5-year intervals to 2030.
2005	O&M Supply	36,000	Existing 7.7-mgd and new 2.6-mgd flow.
2005	O&M Treatment	2,380,000	Existing 7.7-mgd and new 2.6-mgd flow.
2005	Abandon Facilities	0	CF #1, 2, and 3 supply and existing 12-mgd treatment plant. No salvage value.
2005	Capital Costs	858,000	Expand supply to 24 mgd (RRN and RLR).
		33,700,000	New 24-mgd treatment plant.
2005	O&M Supply	22,000	For 10.3-mgd flow. Increases linearly to 2030 value.
2005	O&M Treatment	2,110,000	For 10.3-mgd flow. Increases linearly to 2030 value.
2030	O&M Supply	26,000	For 13.7-mgd flow.
2030	O&M Treatment	2,680,000	For 13.7-mgd flow.
2030	Salvage	678,000	RRN low-head dam and land.
East Grand Forks			
1980	O&M Supply	5,000	For existing 1.5-mgd flow. Increases linearly to 2005 value.
1980	O&M Treatment	564,000	For existing 1.5-mgd flow. Increases linearly to 2005 value.
1990	Capital Costs	4,090,000	Refurbish existing 4-mgd treatment plant.
2005	Capital Costs	269,000	New 7-mgd supply.
		12,100,000	New 6-mgd treatment plant.
2005	O&M Supply	6,000	For 2.1-mgd flow. Increases linearly to 2030 value.
2005	O&M Treatment	663,000	For 2.1-mgd flow. Increases linearly to 2030 value.
2030	O&M Supply	8,000	For 2.9-mgd flow.
2030	O&M Treatment	778,000	For 2.9-mgd flow.
2030	Salvage	135,000	Supply.
Shared Facilities			
1985	O&M Storage	20,000	Maintain RLR low-head dam.
1990	Capital Costs	3,140,000	Replace RLR low-head dam.
1990	O&M Storage	20,000	Maintain RLR low-head dam in eight 5-year intervals to 2030.
2030	Salvage	628,000	RLR low-head dam.
Grand Forks Air Force Base			
1980	Capital Costs	6,290,000	For supply, 15.5 miles of 15" pipe from Grand Forks to base.
1980	O&M Supply	19,000	For existing 16" and new 15" pipe. Uniform to 2030.
Equivalent Annual Cost		5,320,000	

Notes: (1) Components of supply are intake structures and water transmission lines.
RRN - Red River of the North
RLR - Red Lake River
Unless otherwise stated, O&M costs are assumed to be applied annually.

Source: Stanley Consultants, Inc.

ALTERNATIVE I-B-1-b

This alternative adds a granular activated carbon process to all water treatment plants needed in alternative I-A-1-b. This process is capable of satisfying the proposed advanced drinking water standards.

Table 33 summarizes the proposed schedule of improvements, their costs, and the design criteria for this alternative. The conceptual plan is the same as shown on figure 32.

ALTERNATIVE I-B-1-c

This alternative adds a granular activated carbon process to all water treatment plants needed in alternative I-A-1-c. This process is capable of satisfying the proposed advanced drinking water standards.

Table 34 summarizes the proposed schedule of improvements, their costs, and the design criteria for this alternative. The conceptual plan is the same as shown on figure 33.

ALTERNATIVE I-B-2-a

This alternative is the same as alternative I-B-1-a except water conservation practices are implemented. Smaller capacity facilities are needed.

Table 35 summarizes the proposed schedule of improvements, their costs, and the design criteria for this alternative. The conceptual plan is the same as shown on figure 31.

ALTERNATIVE I-B-2-b

This alternative is the same as alternative I-B-1-b except water conservation practices are implemented. Smaller capacity facilities are needed.

Table 36 summarizes the proposed schedule of improvements, their costs, and the design criteria for this alternative. The conceptual plan is the same as shown on figure 32.

Table 33 - Alternative I-B-1-b proposed improvements and costs

Year	Item	Cost ($)	Notes(1)
Grand Forks			
1980	O&M Supply	23,000	For existing 7.7-mgd flow. Uniform to 2005.
1980	O&M Treatment	1,560,000	For existing 7.7-mgd flow. Uniform to 2005.
1985	Capital Costs	170,000	Refurbish GF #3 supply.
1990	Capital Costs	80,000	Refurbish GF #1 supply.
		6,510,000	Refurbish existing 12-mgd treatment plant.
2005	Abandon Facilities	0	GF #1, 2, and 3 supply and existing 12-mgd treatment plant. No salvage value.
East Grand Forks			
1980	O&M Supply	5,000	For existing 1.5-mgd flow. Increases linearly to 2005 value.
1980	O&M Treatment	564,000	For existing 1.5-mgd flow. Increases linearly to 2005 value.
1990	Capital Costs	3,990,000	Refurbish existing 4 mgd treatment plant.
2005	O&M Supply	6,000	For 2.1-mgd flow.
2005	O&M Treatment	663,000	For 2.1-mgd flow.
2005	Abandon Facilities	0	Supply and existing 4-mgd treatment plant. No salvage value.
Combined Facilities			
1980	Capital Costs	12,700,000	New 6-mgd treatment plant and land.
		1,569,000	Supply for 6-mgd pumping (RRN).
1980	O&M Supply	2,000	For 0-mgd flow. Increases linearly to 2005 value.
1980	O&M Treatment	0	For 0-mgd flow. Increases linearly to 2005 value.
1985	O&M Storage	20,000	Maintain RRN low-head dam.
		20,000	Maintain RLR low-head dam.
1990	Capital Costs	2,510,000	Replace RRN low-head dam.
		3,140,000	Replace RLR low-head dam.
1990	O&M Storage	20,000	Maintain RRN low-head dam in eight 5-year intervals to 2030.
		20,000	Maintain RLR low-head dam in eight 5-year intervals to 2030.
2005	O&M Supply	12,000	For 2.6-mgd flow.
2005	O&M Treatment	816,000	For 2.6-mgd flow.
2005	Relocation of GF/EGF Supply/Treatment to New Site		
2005	Capital Costs	2,228,000	Expand supply to 30 mgd (RRN and RLR).
		40,700,000	New 30-mgd treatment plant.
2005	O&M Supply	35,000	For 12.4-mgd flow. Increases linearly to 2030 value.
2005	O&M Treatment	2,440,000	For 12.4-mgd flow. Increases linearly to 2030 value.
2030	O&M Supply	45,000	For 16.7-mgd flow.
2030	O&M Treatment	3,140,000	For 16.7-mgd flow.
2030	Salvage	2,290,000	Low-head dams, supply, land.
Grand Forks Air Force Base			
1980	Capital Costs	6,290,000	For supply, 15.5 miles of 15" pipe from GF to base.
1980	O&M Supply	19,000	Existing 16" and new 15" pipe. Uniform to 2030.
Equivalent Annual Cost		5,210,000	

Notes: (1) Components of supply are intake structures and water transmission lines.
RRN - Red River of the North
RLR - Red Lake River
Unless otherwise stated, O&M costs are assumed to be applied annually.

Source: Stanley Consultants, Inc.

Table 34 - Alternative I-B-1-c proposed improvements and costs

Year	Item	Cost ($)	Notes(1)
Grand Forks			
1980	O&M Supply	23,000	For existing 7.7-mgd flow. Uniform to 1990.
1980	O&M Treatment	1,560,000	For existing 7.7-mgd flow. Uniform to 1990.
1985	Capital Costs	170,000	Refurbish GF #3 supply.
1990	Abandon Facilities	0	GF #1, 2, and 3 supply and existing 12-mgd treatment plant. No salvage value.
East Grand Forks			
1980	O&M Supply	5,000	For existing 1.5-mgd flow. Increases linearly to 1990 value.
1980	O&M Treatment	564,000	For existing 1.5-mgd flow. Increases linearly to 1990 value.
1990	O&M Supply	6,000	For 1.7-mgd flow.
1990	O&M Treatment	602,000	For 1.7-mgd flow.
1990	Abandon Facilities	0	Supply and existing 4-mgd treatment plant. No salvage value.
Combined Facilities			
1980	Capital Costs	12,700,000	New 6-mgd treatment plant and land.
		1,580,000	Supply for 6-mgd pumping (RRN).
1980	O&M Supply	2,000	For 0-mgd flow. Increases linearly to 1990 value.
1980	O&M Treatment	0	For 0-mgd flow. Increases linearly to 1990 value.
1985	O&M Storage	20,000	Maintain RRN low-head dam.
		20,000	Maintain RLR low-head dam.
1990	O&M Supply	5,000	For 1.0-mgd flow.
1990	O&M Treatment	326,000	For 1.0-mgd flow.
1990	Capital Costs	2,510,000	Replace RRN low-head dam.
		3,140,000	Replace RLR low-head dam.
		2,240,000	Expand supply to 30 mgd (RRN and RLR).
		33,700,000	Replace GF/EGF treatment plants. Capacity 18 mgd.
1990	O&M Storage	20,000	Maintain RRN low-head dam in eight 5-year intervals to 2030.
		20,000	Maintain RLR low-head dam in eight 5-year intervals to 2030.
1990	O&M Supply	30,000	For 10.3-mgd flow. Increases linearly to 2030 value.
1990	O&M Treatment	2,110,000	For 10.3-mgd flow. Increases linearly to 2015 value.
2005	Capital Costs	4,760,000	Refurbish original 6-mgd treatment cell.
2015	Capital Costs	44,000,000	Replace all treatment to 33-mgd capacity.
2015	O&M Treatment	2,710,000	For 14-mgd flow. Increases linearly to 2030 value.
2030	O&M Supply	45,000	For 16.7-mgd flow.
2030	O&M Treatment	3,140,000	For 16.7-mgd flow.
2030	Salvage	19,100,000	Low-head dams, supply, treatment, land.
Grand Forks Air Force Base			
1980	Capital Costs	6,290,000	For supply, 15.5 miles of 15" pipe from GF to base.
1980	O&M Supply	19,000	For supply existing 16" and new 15" pipe. Uniform to 2030.
Equivalent Annual Cost		5,820,000	

Notes: (1) Components of supply are intake structures and water transmission lines.
RRN - Red River of the North
RLR - Red Lake River
Unless otherwise stated, O&M costs are assumed to be applied annually.

Source: Stanley Consultants, Inc.

Table 35 - Alternative I-B-2-a proposed improvements and costs

Year	Item	Cost ($)	Notes(1)
Grand Forks			
1980	Capital Costs	10,000,000	New 4-mgd treatment plant and land.
		1,562,000	Supply at 4-mgd pumping (RRN).
1980	O&M Supply	24,000	For existing 7.1-mgd and new 0-mgd flow. Increases linearly to 2005 value.
1980	O&M Treatment	1,480,000	For existing 7.1-mgd and new 0-mgd flow. Increases linearly to 2005 value.
1985	Capital Costs	170,000	Refurbish GF #3 supply.
1985	O&M Storage	20,000	Maintain RRN low-head dam.
1990	Capital Costs	2,510,000	Replace RRN low-head dam.
		80,000	Refurbish GF #1 supply.
		6,500,000	Refurbish existing 12-mgd treatment plant.
1990	O&M Storage	20,000	Maintain RRN low-head dam in eight 5-year intervals to 2030.
2005	O&M Supply	30,000	Existing 7.1-mgd and new 2.3-mgd flow.
2005	O&M Treatment	2,240,000	Existing 7.1-mgd and new 2.3-mgd flow.
2005	Abandon Facilities	0	GF #1, 2, and 3 supply and existing 12-mgd treatment plant. No salvage value.
2005	Capital Costs	944,000	Expand supply to 22-mgd (RRN and RLR).
		31,100,000	New 22-mgd treatment plant.
2005	O&M Supply	26,000	For 9.4-mgd flow. Increases linearly to 2030 value.
2005	O&M Treatment	1,970,000	For 9.4-mgd flow. Increases linearly to 2030 value.
2030	O&M Supply	34,000	For 12.6-mgd flow.
2030	O&M Treatment	2,480,000	For 12.6-mgd flow.
2030	Salvage	1,050,000	RRN low-head dam and land.
East Grand Forks			
1980	O&M Supply	4,000	For existing 1.4-mgd flow. Increases linearly to 2005 value.
1980	O&M Treatment	409,000	For existing 1.4-mgd flow. Increases linearly to 2005 value.
1990	Capital Costs	3,980,000	Refurbish existing 4-mgd treatment plant.
2005	Capital Costs	264,000	New 7-mgd supply.
		10,900,000	New 5-mgd treatment plant.
2005	O&M Supply	6,000	For 1.9-mgd flow. Increases linearly to 2030 value.
2005	O&M Treatment	635,000	For 1.9-mgd flow. Increases linearly to 2030 value.
2030	O&M Supply	8,000	For 2.6-mgd flow.
2030	O&M Treatment	740,000	For 2.6-mgd flow.
2030	Salvage	103,000	Supply.
Shared Facilities			
1985	O&M Storage	20,000	Maintain RLR low-head dam.
1990	Capital Costs	3,140,000	Replace RLR low-head dam.
1990	O&M Storage	20,000	Maintain RLR low-head dam in eight 5 year intervals to 2030.
2030	Salvage	627,000	RLR low-head dam
Grand Forks Air Force Base			
1980	Capital Costs	6,290,000	For supply, 15.5 miles of 15" pipe from GF to base.
1980	O&M Supply	19,000	Existing 16" and new 15" pipe. Uniform to 2030.
Equivalent Annual Cost		[illegible],920,000	

Notes: (1) Components of supply are intake structures and water transmission lines.
RRN Red River of the North
RLR Red Lake River
Unless otherwise stated, O&M costs are assumed to be applied annually

Source: Stanley Consultants, Inc

Table 36 - Alternative I-B-2-b proposed improvements and costs

Year	Item	Cost ($)	Notes(1)
Grand Forks			
1980	O&M Supply	22,000	For existing 7.1-mgd flow. Uniform to 2005.
1980	O&M Treatment	1,480,000	For existing 7.1-mgd flow. Uniform to 2005.
1985	Capital Costs	170,000	Refurbish GF #3 supply.
1990	Capital Costs	80,000	Refurbish GF #1 supply.
		6,500,000	Refurbish existing 12-mgd treatment plant.
2005	Abandon Facilities	0	GF #1, 2, and 3 supply and existing 12-mgd treatment plant. No salvage value.
East Grand Forks			
1980	O&M Supply	4,000	For existing 1.4-mgd flow. Increases linearly to 2005 value.
1980	O&M Treatment	557,000	For existing 1.4-mgd flow. Increases linearly to 2005 value.
1990	Capital Costs	3,980,000	Refurbish existing 4-mgd treatment plant.
2005	O&M Supply	6,000	For 1.9-mgd flow.
2005	O&M Treatment	635,000	For 1.9-mgd flow.
2005	Abandon Facilities	0	Supply and existing 4-mgd treatment plant. No salvage value.
Combined Facilities			
1980	Capital Cost	10,000,000	New 4-mgd treatment plant and land.
		1,552,000	Supply for 4-mgd pumping (RRN).
1980	O&M Supply	2,000	For 0-mgd flow. Increases linearly to 2005 value.
1980	O&M Treatment	0	For 0-mgd flow. Increases linearly to 2005 value.
1985	O&M Storage	20,000	Maintain RRN low-head dam.
		20,000	Maintain RLR low-head dam.
1990	Capital Costs	2,510,000	Replace RRN low-head dam.
		3,140,000	Replace RLR low-head dam.
1990	O&M Storage	20,000	Maintain RRN low-head dam in eight 5-year intervals to 2030.
		20,000	Maintain RLR low-head dam in eight 5-year intervals to 2030.
2005	O&M Supply	9,000	For 2.3-mgd flow.
2005	O&M Treatment	760,000	For 2.3-mgd flow.
2005	Relocation of GF/EGF Supply/Treatment to New Site		
2005	Capital Costs	2,024,000	Expand supply to 26 mgd (RRN and RLR).
		35,900,000	New 26-mgd treatment plant.
2005	O&M Supply	32,000	For 11.3-mgd flow. Increases linearly to 2030 value.
2005	O&M Treatment	2,270,000	For 11.3-mgd flow. Increases linearly to 2030 value.
2030	O&M Supply	42,000	For 15.2-mgd flow.
2030	O&M Treatment	2,890,000	For 15.2-mgd flow.
2030	Salvage	2,130,000	Low-head dams, supply, land.
Grand Forks Air Force Base			
1980	Capital Costs	6,290,000	For supply, 15.5 miles of 15" pipe from GF to base.
1980	O&M Supply	19,000	Existing 16" and new 15" pipe. Uniform to 2030.
Equivalent Annual Cost		4,820,000	

Notes: (1) Components of supply are intake structures and water transmission lines.
RRN - Red River of the North
RLR - Red Lake River
Unless otherwise stated, O&M costs are assumed to be applied annually.

Source: Stanley Consultants, Inc.

ALTERNATIVE I-B-2-c

This alternative is the same as alternative I-B-1-c except water conservation practices are implemented. Smaller capacity facilities are needed.

Table 37 summarizes the proposed schedule of improvements, their costs, and the design criteria for this alternative. The conceptual plan is the same as shown on figure 33.

ALTERNATIVE II COMBINATIONS

All alternative II combinations are similar to the alternative I combinations except Garrison Diversion water supplements the Red River of the North natural flow.

The alternative II combinations are not fully described and costed because supplemental flow augmentation is not required. The low-flow frequency analysis described previously indicates that natural surface water flows could satisfy the GF/EGF urban area water demands without supplementation. Therefore, Garrison Diversion water supplementing to Red River of the North is not required.

ALTERNATIVE III COMBINATIONS

All alternative III combinations are similar to the alternative I and II combinations except groundwater is substituted as the source of supply. The Elk Valley aquifer located west of the urban area and the Beach Ridge aquifer located east of the urban area were analyzed previously.

The alternative III combinations are not fully described and costed because the groundwater sources are not capable of satisfying the GF/EGF urban area water demands. The analysis indicates that the rate of recharge to these aquifers is too small. Therefore, the groundwater sources in the area cannot be used.

Table 37 - Alternative I-B-2-c proposed improvements and costs

Year	Item	Cost ($)	Notes(1)
Grand Forks			
1980	O&M Supply	22,000	For existing 7.1-mgd flow. Uniform to 1990.
1980	O&M Treatment	1,480,000	For existing 7.1-mgd flow. Uniform to 1990.
1985	Capital Costs	170,000	Refurbish GF #3 supply.
1990	Abandon Facilities	0	GF #1, 2, and 3 supply and existing 12-mgd treatment plant. No salvage value.
East Grand Forks			
1980	O&M Supply	4,000	For existing 1.4-mgd flow. Increases linearly to 1990 value.
1980	O&M Treatment	557,000	For existing 1.4-mgd flow. Increases linearly to 1990 value.
1990	O&M Supply	6,000	For 1.6-mgd flow.
1990	O&M Treatment	590,000	For 1.6-mgd flow.
1990	Abandon Facilities	0	Supply and existing 4-mgd treatment plant. No salvage value.
Combined Facilities			
1980	Capital Costs	10,000,000	New 4-mgd treatment plant and land.
		1,552,000	Supply for 4-mgd pumping (RRN).
1980	O&M Supply	2,000	For 0-mgd flow. Increases linearly to 1990 value.
1980	O&M Treatment	0	For 0-mgd flow. Increases linearly to 1990 value.
1985	O&M Storage	20,000	Maintain RRN low-head dam.
		20,000	Maintain RLR low-head dam.
1990	O&M Supply	4,000	For 0.8-mgd flow.
1990	O&M Treatment	415,000	For 0.8-mgd flow.
1990	Capital Costs	2,510,000	Replace RRN low-head dam.
		3,130,000	Replace RLR low-head dam.
		2,024,000	Expand supply to 26 mgd (RRN and RLR).
		26,900,000	Replace GF/EGF treatment plants. Capacity 18 mgd.
1990	O&M Storage	20,000	Maintain RRN low-head dam in eight 5-year intervals to 2030.
		20,000	Maintain RLR low-head dam in eight 5-year intervals to 2030.
1990	O&M Supply	36,000	For 9.5-mgd flow. Increases linearly to 2030 value,
1990	O&M Treatment	1,980,000	For 9.5-mgd flow. Increases linearly to 2015 value.
2005	Capital Costs	4,750,000	Refurbish original 4-mgd treatment cell.
2015	Capital Costs	37,900,000	Replace all treatment to 28-mgd capacity.
2015	O&M Treatment	2,500,000	For 12.7-mgd flow. Increases linearly to 2030 value.
2030	O&M Supply	48,000	For 15.2-mgd flow.
2030	O&M Treatment	2,890,000	For 15.2-mgd flow.
2030	Salvage	16,700,000	Low-head dams, supply, treatment, land.
Grand Forks Air Force Base			
1980	Capital Costs	6,290,000	For supply, 15.5 miles of 15" pipe from GF to base.
1980	O&M Supply	19,000	For supply existing 16" and new 15" pipe. Uniform to 2030.
Equivalent Annual Cost		5,100,000	

Notes: (1) Components of supply are intake structures and water transmission lines.
RRN - Red River of the North
RLR - Red Lake River
Unless otherwise stated, O&M costs are assumed to be applied annually.

Source: Stanley Consultants, Inc.

SUMMARY OF EQUIVALENT ANNUAL COSTS

The equivalent annual cost of each alternative is summarized in table 40, which is included in a later section.

IMPACT ASSESSMENT

GENERAL

This section summarizes the impact assessment of the water supply and treatment alternatives. The environmental, social, and economic changes associated with each alternative are identified and measured. The impact assessments are summarized in matrix form.

The impact assessment is divided into two components to simplify the presentation. First, the water supply and treatment design condition alternatives are considered. Second, separate and combined water supply and treatment system alternatives are assessed. These alternatives involve only surface water as the supply source. The technical analysis determined that supplementing Red River of the North with Garrison Diversion water was not required. Also, the Elk Valley and Beach Ridge aquifers are not feasible supply sources for the GF/EGF urban area because their rate of recharge is too small.

Table 38 is the impact analysis matrix for three water supply and treatment design condition alternatives. These include:

1. No action. Interim primary drinking water standards must be met with this alternative and no water conservation practices are included.
2. Proposed advanced drinking water standards must be satisfied with this alternative.
3. Alternative 1 or 2 with water conservation practices implemented. The effect of water conservation practices on Alternative 1 or 2 is essentially the same.

Table 38 - Impact assessment of water system design condition alternatives

Impact	No Action(1)	Advanced Standards	With Conservation
Environmental			
Land	No effect.	Minimal.	Minimal.
Man-made Resources	No effect.	No effect.	No effect.
Natural Resources	No effect.	Increased chemical & energy requirements.	Decreased consumption will increase streamflow. Decreased chemical and energy requirements for treatment.
Water Quality	No effect.	No effect.	Enhanced during low flow.
Air Quality	No effect.	No effect.	No effect.
Wildlife	No effect.	No effect.	No effect.
Hydrologic	No effect.	No effect.	Increased streamflow.
Public Health	No effect.	Greater protection.	No effect.
Social			
Noise	No effect.	No effect.	No effect.
Displacement of People	No effect.	No effect.	No effect.
Aesthetics	No effect.	No effect.	May change.
Community Cohesion	No effect.	No effect.	May change.
Community Growth	No effect.	May be impaired.	May be impaired.
Historical & Archaeological	No effect.	No effect.	No effect.
Transportation	No effect.	No effect.	No effect.
Institutional Relationships	No effect.	No effect.	No effect.
Public Acceptance	No change.	Decreased.	Decreased.
Economic			
Property Values	No effect.	No effect.	No effect.
Tax Revenues	No effect.	No effect.	No effect.
Public Facilities & Services	No effect.	No effect.	No effect.
Business & Industrial Activities	No effect.	May be impaired.	May be impaired.
Employment	No effect.	May be impaired.	May be impaired.
Agricultural Land Lost	No effect.	Minimal.	No effect.
Regional Growth	Not constrained.	May be impaired.	May be impaired.

Notes: (1) Includes the design conditions of Interim Primary Drinking Water standards and without water conservation practices.

Table 39 presents the impact analysis matrix for the separate versus combined water supply and treatment alternatives. Grand Forks and East Grand Forks may expand and continue using their individual systems or they may join a regional system that serves both cities. The "without project" alternative projects a future in which no expansion of existing facilities is made.

ENVIRONMENTAL

Table 38 indicates that no significant environmental impacts are associated with the "no action" alternative. If harmful levels of organic contaminants are found in the supplies, advanced treatment would be needed. However, extensive water quality monitoring is required to define the development of potential health problems. Table 37 shows that increased chemical and energy requirements associated with advanced treatment are expected with granular activated carbon use and recharge. A higher level of water treatment should result in greater protection of the public health.

Water conservation reduces the consumption of water Because less water is treated and pumped, the treatment plant chemical and energy requirements are reduced. Also with water conservation, higher flows in the Red Lake River and the Red River of the North can be maintained. This is particularly significant during low-flow periods. A 10-percent decrease in water consumption could result in a 30-percent increase in river flow during low-flow periods. The increased flow improves water quality by increasing the assimilative capacity of the rivers, and a more desirable environment for aquatic biota can be maintained.

Table 39 indicates that the "without project" alternative has no additional impact on the environment with separate or combined system alternatives. Location of a new treatment facility will

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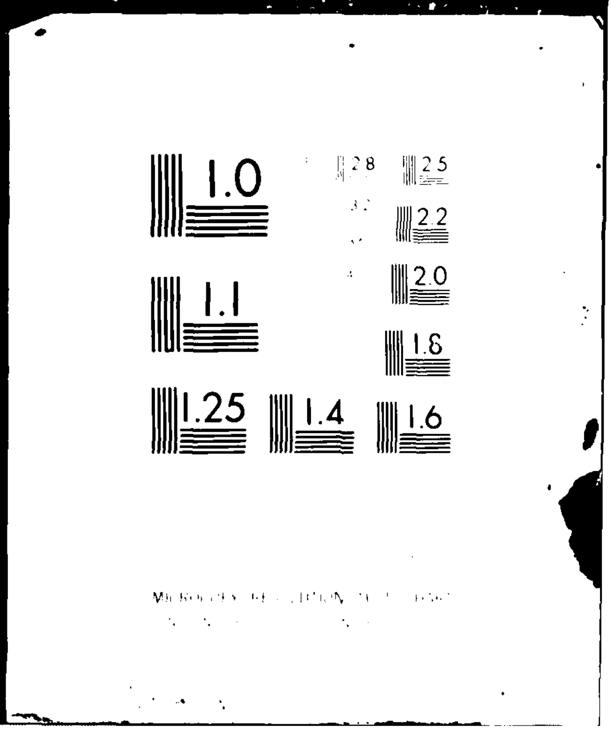


Table 39 - Impact assessment of separate and combined system alternatives

Impact	No Action[1]	Separate Systems	Combined System
Environmental			
Land	No effect.	Will affect about 20 acres of prime agricultural land for new treatment plants.	Will affect about 15 acres of prime agricultural land for new treatment plant.
Man-made Resources	No effect.	No effect.	No effect.
Natural Resources	No effect.	Additional consumptive use; possible adverse effect at low flow; additional chemicals required for treatment.	Additional consumptive use; possible adverse effect at low flow; additional chemicals required for treatment.
Water Quality	No effect.	Possible adverse effect at low flow.	Possible adverse effect at low flow.
Air Quality	No effect.	During construction.	During construction.
Wildlife	No effect.	No effect.	No effect.
Hydrologic	No effect.	Increased consumption use reduces river flow.	Increased consumption reduces river flow.
Social			
Noise	No effect.	During construction.	During construction.
Displacement of People	No effect.	No effect.	No effect.
Aesthetics	No effect.	May decrease locally due to large building.	May decrease locally due to large building.
Community Cohesion	May be impaired.	No change.	May change.
Community Growth	Impaired.	No constraint.	No constraint.
Historical & Archaeological	No effect.	No known effect.	No known effect.
Transportation	No effect.	During construction.	During construction.
Institutional Relationships	No effect.	No effect.	Will change.
Economic			
Property Values	May be impaired.	No change.	No change.
Tax Revenue	May be impaired.	May increase.	May increase.
Public Facilities & Services	Impaired.	May enhance.	May enhance.
Business & Industrial Activities	Constrained.	No constraint.	No constraint.
Employment	May not increase.	No constraint.	No constraint.
Agricultural Land Lost	No effect.	About 20 acres of prime agricultural.	About 15 acres of prime agricultural.
Regional Growth	Constrained.	No constraint.	No constraint.

Notes: (1) Includes continued use of existing systems, but no expansions for existing water supply and treatment systems.

remove about 10 to 15 acres of prime agricultural land from production. Dust levels will increase during construction. However, the study area is classified as an attainment area for total suspended particulates, so the impact from construction activities will be minimal.

New separate or combined facilities will increase the consumptive use of water. In addition, chemical and energy use will increase and Red Lake River and Red River of the North water treatment flows will decrease. The average daily water use for the GF/EGF area is only 1 percent of the average annual flow in the Red River of the North at Grand Forks. However, up to 75 percent of the river flow will be withdrawn during low-flow periods. Therefore, the natural resources value and water quality may be impaired during extreme low-flow periods.

SOCIAL

Table 38 shows that the "no action" alternative with interim primary drinking water standards will have no significant effect on social factors. Public acceptance of proposed advanced water treatment standards will be decreased because of higher water bills. Higher water bills could slow community growth as prospective large water users may be discouraged from locating in the area. These proposed regulations have caused considerable controversy in the water treatment field, primarily over the necessity and the economic impact of the requirements.

Public acceptance of water conservation practices is hard to achieve because water use habits must change. Extensive public education effort and ordinances requiring water conservation practices increase public acceptance. Rate structures that include excess or peak-use charges effectively reduce water use; however, public acceptance is reduced. Also, generally the success of water conservation programs is directly proportional to the degree that users perceive that there is a problem. If water is discharging

over the low-head dam during nondrought conditions, acceptance of water conservation is reduced. If user costs can be reduced by significantly reducing capital and O&M costs, public acceptance of water conservation is increased.

Table 39 shows that community growth will be impaired if water supply and treatment alternatives are not developed to meet all water demands. The Grand Forks water treatment plant is currently at capacity. The East Grand Forks treatment facility will reach capacity by the year 2005. Without expanded facilities, new service connections must be prohibited and/or water conservation practices must be implemented.

With the "without project" alternative, community cohesion may be impaired because of declining social character of the area. Because facilities are not expanded, friction between the two cities may develop because Grand Forks cannot continue to grow while East Grand Forks will be able to satisfy all its projected water needs through year 2005.

Expanding water supply and treatment facilities will eliminate the constraint to projected community growth. During construction activities, noise and heavy equipment traffic will increase near the construction site. The large structure housing the treatment facilities will be located within sight of a residential development. Negative aesthetic impacts can be mitigated by careful architectural treatment and landscaping.

A combined regional system will change the existing urban area institutional relationships. Political and social alliances will change but cooperation between the cities will be enhanced. A formal agreement must be worked out between the participating entities. Legislative action by either State may be necessary to modify the existing water use permits to make them more compatible with bi-State needs.

ECONOMIC

Table 38 shows that the "no action" alternative will have no significant impact on economic factors. The proposed advanced standards alternative will increase water rates. Businesses and industries that use large amounts of water may not locate in the GF/EGF area because of the high water rates. This may also have negative impacts on employment and regional growth of the area.

Water conservation practices may also have a negative impact on the economy of the area by restricting water use. Business and industrial activities, employment, and regional growth may be impaired.

Table 39 indicates that the "without project" alternative will constrain business and industrial activities because they cannot grow. Also, regional growth and employment will be impaired. These constraints may result in the reduction of property values and the associated tax base. Because the tax revenues may be reduced, public facilities and services, such as police, streets, and snow removal, cannot be maintained and improved.

The separate and/or combined system alternatives will use about 10 to 15 acres of prime agricultural land and remove it from production.

However, several beneficial economic impacts will result because adequate water supplies will be available to satisfy projected growth needs. There will be no economic constraints to growth in business and industrial activities, employment, and tax revenues. General regional growth can increase and public facilities and services can be enhanced.

EVALUATION

GENERAL

This section summarizes the evaluation of the water supply and treatment alternatives. The evaluations involve the beneficial and adverse impacts of each alternative and compare the impacts to the "no action" or "without project" conditions and to the other plans. The evaluations consider the subjective value of the impacts as perceived by the public. The relative contributions of the alternative plans are considered and, where applicable, trade-offs are made. The evaluations consider both the impacts summarized in the previous section and the public perceptions of those impacts.

The evaluation process includes the analysis of the alternative plans in relation to planning objective fulfillment, national economic development, environmental quality, regional development, and social well-being. Specific evaluation criteria are used to establish the overall desirability of the alternative plans.

PLANNING OBJECTIVE FULFILLMENT

The objective of the water supply study is to develop a plan for providing an adequate quantity and quality water supply to the GF/EGF urban area. The plan should be the most cost-effective alternative while recognizing social, environmental, technical, political, and institutional concerns.

The surface water supply alternatives fulfill the planning objective of providing an adequate quantity of water. The low-flow frequency analysis summarized previously indicates that the low-flow augmentation reservoirs built and improved in the

early 1950's (particularly the Red Lakes Reservoir) can satisfy projected urban area water demands through year 2030, except during extreme droughts. During extreme droughts, existing in-channel storage at Grand Forks and East Grand Forks can adequately supplement streamflows to satisfy the water demands. With proper treatment to satisfy water quality standards, an adequate quality water supply can be provided.

Garrison Diversion water supplementing the Red River of the North streamflow is not required to satisfy the GF/EGF urban area water demands based on the above-referenced low-flow analyses. Also, the political and environmental constraints that are preventing the implementation of the project seriously reduce the reliability of this supply source. Therefore, this supply source does not fulfill the planning objective.

The Elk Valley and Beach Ridge aquifers cannot produce the quantity of water needed to supply the urban area. The rate of recharge to these aquifers limits their capacity. Therefore, these groundwater supplies do not fulfill the planning objective. Using the groundwater sources as supplementary supplies is not cost effective because of the long transmission distance between the aquifers and the urban area and the required well field size.

Water conservation reduces the water demand so smaller capacity water supply sources and treatment facilities are required. Water conservation practices under nondrought conditions are projected to reduce maximum day water demands by about 10 percent. (Water conservation and rationing measures that can further reduce water usage are listed later.) Although an adequate water supply source is available, water conservation practices are cost effective because they reduce the use of valuable natural resources including water, chemicals and energy. Capital expenditures are reduced when the capacities of water intake, pumping, transmission, and treatment facilities are reduced. Implementation of water

conservation practices requires extensive involvement from local citizens and local governments. Water use habits will be changed, and some reduced industrial use will be required. However, implementation of water conservation practices does generally satisfy the planning objective.

The separate or combined water supply and treatment system alternatives also satisfy the planning objective. Both types of systems can produce an adequate quantity and quality water. Under separate systems, existing institutional arrangements would continue. Under the combined systems, institutional arrangements and socioeconomic alliances would be changed.

ECONOMICS AND NATIONAL ECONOMIC DEVELOPMENT

Table 40 summarizes the equivalent annual cost of the water supply and treatment alternatives considered. The subset of the three separate or combined alternatives under each major category can be compared directly. These alternatives are options which satisfy the same water quality standards and involve the same level of water conservation. However, subset alternatives under different major categories cannot be compared directly because the design conditions are different. For example, regulatory agencies set water quality standards which must be satisfied. Local officials do not have the option to choose which water quality standard they will follow. Therefore, comparison between the different standards only indicates that higher costs are associated with higher standards. Similarly, alternatives with water conservation result in cost savings. Table 40 indicates that about $300,000 per year in equivalent annual costs could be saved by implementing water conservation programs. However, the local communities and their citizens must decide whether water conservation practices will be implemented. Also, under the President's water policy, Federal agencies might not provide financial assistance unless water conservation is included in water projects.

Table 40 - Equivalent annual cost summary

	I Surface Water ($)	II Garrison Diversion	III Ground-water
A. Interim Primary Drinking Water Standards			
1. Without Water Conservation Practices		Supplement flow augmentation is not required.	This source is not feasible due to lack of recharge to the Elk Valley and/or Beach Ridge Aquifers.
a. Separate supply and treatment	4,460,000		
b. Combined supply and treatment in year 2005	4,400,000		
c. Combined supply and treatment in year 1990	4,830,000		
2. With Water Conservation Practices			
a. Separate supply and treatment	4,170,000		
b. Combined supply and treatment in year 2005	4,070,000		
c. Combined supply and treatment in year 1990	4,330,000		
B. Proposed Advanced Drinking Water Standards			
1. Without Water Conservation Practices			
a. Separate supply and treatment	4,970,000		
b. Combined supply and treatment in year 2005	4,820,000		
c. Combined supply and treatment in year 1990	5,100,000		
2. With Water Conservation Practices			
a. Separate supply and treatment	5,320,000		
b. Combined supply and treatment in year 2005	5,210,000		
c. Combined supply and treatment in year 1990	5,820,000		

Source: Stanley Consultants, Inc.

Table 40 indicates that the most economical alternative is for Grand Forks and East Grand Forks to form a regional water supply and treatment system serving both cities in year 2005. This subset alternative is the most economical under each major category. Alternatives I-A-1-b, I-A-2-b, I-B-1-b, and I-B-2-b have the lowest equivalent annual cost of their respective subsets.

An adequate quantity and quality water supply will allow continued economic and industrial growth in the area. National economic development benefits include potential increased output of goods and services on the local, regional, State, and national levels.

Without additional water supply and treatment facilities, the economic development accounts would be adversely affected, and business and industrial activities, employment, and regional growth may be impaired. Direct adverse economic impacts include

expenditure of capital and O&M funds which must be diverted from other uses.

Indirect economic impacts are increased expenditures for chemicals and energy. These impacts are reduced by water conservation practices because the water quantity treated is reduced. Advanced water treatment greatly increases energy consumption.

ENVIRONMENTAL QUALITY

The environmental quality of the area is not affected greatly by either the "without project" alternative or proposed improvements. The proposed improvements allow further reduction of streamflow which may adversely affect downstream water quality and uses during low-flow conditions. Additional natural resources will be consumed including water, chemicals, and energy. Water treatment plant expansions will remove 10 to 15 acres of prime agricultural land from production. Other environmental impacts occur during construction and are localized and temporary.

REGIONAL DEVELOPMENT

Adequate water supplies are essential for continued regional development. Growth in the immediate urban area, the study area, and the region would be hindered without expanded water supply and treatment facilities. Expanded water systems will attract more industrial, employment, and economic growth to the immediate urban area.

With joint water systems, the regional growth patterns may be changed because decisions on water supply for new development would be made by one agency rather than two communities.

SOCIAL WELL-BEING

Sufficient quantities of potable water are essential for maintaining the social well-being of the area residents. Each surface water alternative plan can satisfy projected water demands. Expansion of water systems will enhance the prospects for future

business, industrial, and employment growth. Social stability can also be improved by strengthening job security, local governments, community unity, schools, and family unity.

During construction activities, temporary adverse impacts include equipment noise, dust, and traffic congestion. The large building required to house the water treatment plant may reduce the aesthetic appeal and suitability for residential development of adjacent lands.

The least cost alternative that supplies all water demands and benefits the area's economic and social well-being the most should be selected.

INSTITUTIONAL

Continued use of separate water supply and treatment systems will not change existing institutional and management relationships. Existing socioeconomic alliances are also maintained and local competition for economic, industrial, and residential growth will continue. Separate systems preserve local control, local autonomy, and political accountability.

Combined water systems will require changes in existing institutional arrangements. The regional water supply and treatment agency could be organized through a formal agreement. The agreement would specify the arrangements for making decisions, financing, and managing the system. Each participating entity's interests could be protected by establishing fair representation on the governing board. To efficiently carry out its duties, the governing board must cooperate fully with each of the communities involved.

OTHER EVALUATION CRITERIA

The "without project" alternative public acceptability will be reduced because living standards will be reduced. The planning objective cannot be satisfied, so this alternative does not exhibit completeness, effectiveness, or efficiency.

The alternatives involving surface water as the source satisfy the criteria of completeness, effectiveness, certainty, and geographic scope. If the least cost alternative is implemented, the greatest efficiency will be realized. Each of the alternatives involve structural improvements so reversibility of the plans is limited. The improvements will be staged so there is some flexibility to adjust the improvement programs if the needs change. The availability of surface water has been analyzed and indicates that the supply will be adequate.

Alternatives involving water conservation practices are less certain because local users must accept and implement the practices. Water supply alternatives using groundwater and Garrison Diversion water have been eliminated because they lack technical reliability.

The separate and combined water supply and treatment alternatives satisfy the criteria of completeness, effectiveness, and geographic scope. The combined system alternatives exhibit less certainty and public acceptability.

SELECTED PLAN

The recommended alternative to be implemented is based on local reviews and inputs. The process included draft reports; work group meetings; public meetings; and local, regional, State, and Federal agency reviews.

Based on the economic analysis, the selected plan to be initially implemented is Alternative I-A-1-b. Alternative I-A-2-b would become the recommended plan if local governmental agencies implement water conservation measures. Alternative I-B-1-b or I-B-2-b would be utilized if Federal or State regulations for advanced water treatment are imposed. These alternatives are the least cost alternative under each major category of design criteria. Under each alternative, Grand Forks and East Grand Forks will continue to own and operate their own water systems

through year 2005. In year 2005, a regional water supply and treatment system will replace the existing system.

These alternatives are the most cost effective so customer costs are minimized as much as possible. They also maximize the use of existing facilities and replace them when their service lives are exceeded.

IMPLEMENTATION AND RECOMMENDATIONS

GENERAL

Figure 34 presents the conceptual plan of the recommended alternative. Based on the economic analysis and local input and review, the recommended plan to be initially implemented is Alternative I-A-1-b. If the local governmental agencies implement water conservation programs, Alternative I-A-2-b would become the recommended plan. This would have the effect of extending the useful life of those improvements made under Alternative I-A-1-b before water conservation practices were implemented. If Federal and State regulatory agencies require that advanced water quality standards be met, the recommended plan would become Alternative I-B-1-b or I-B-2-b.

The major components, the proposed schedule of improvements, and costs will be summarized following selection of the recommended plan.

WATER SERVICE AGENCIES

The responsibility for implementing the recommended water supply and treatment plan will be initially assigned to the existing water service agencies including:

1. Grand Forks, North Dakota.
2. East Grand Forks, Minnesota.
3. Emerado, North Dakota.
4. Grand Forks Air Force Base, North Dakota.
5. American Crystal Sugar, Minnesota.
6. Burlington Industries, Minnesota.

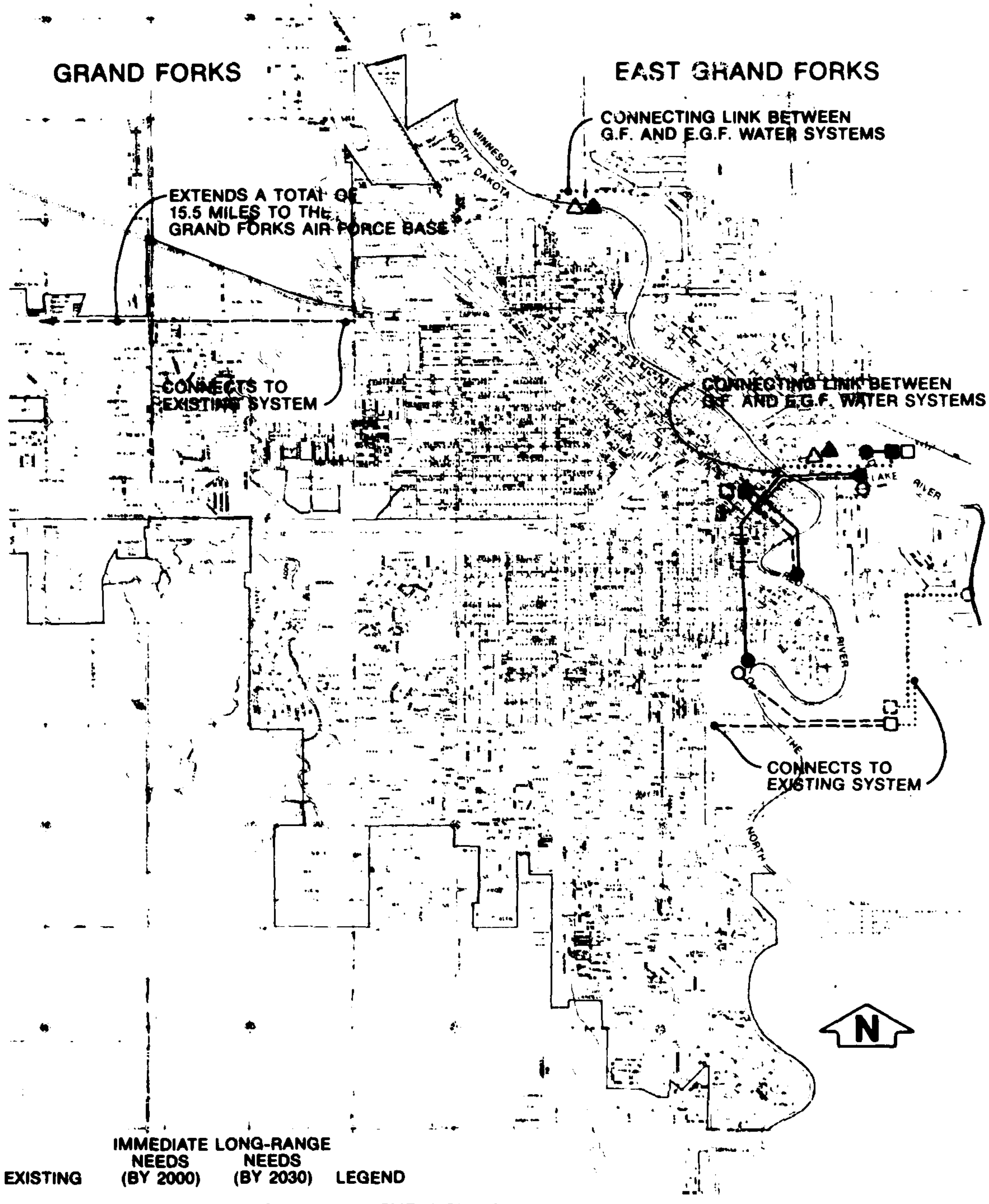
7. Pillsbury Company, North Dakota.
8. Agassiz Water Users Association, North Dakota.
9. Grand Forks-Traill Water Users, Inc., North Dakota.
10. Marshall and Polk Rural Water System, Minnesota.

In year 2005, Grand Forks and East Grand Forks should establish a regional water system to serve both communities. The regional system would be organized through a formal agreement that specifies the management, decision-making, and financial arrangements. The governing board would include representatives from both communities. Grand Forks will continue to supply the Grand Forks Air Force Base. Although both the Grand Forks and East Grand Forks water treatment plants will be operated through year 2005, the local governments could establish a regional agency to manage those facilities before year 2005.

Each water service agency will be responsible for planning, financing, constructing, operating, and maintaining the water supply and treatment facilities within its jurisdiction. Each agency will be responsible for managing its system, raising revenues from its users, and incurring indebtedness as required to construct and operate the water systems. Each agency is also responsible for implementing water conservation practices.

IMPLEMENTATION SCHEDULE

Table 41 presents a cost and implementation schedule for the recommended plan. The recommended improvements include water storage, supply (intake and pumping), transmission, and treatment facilities. Grand Forks must expand its water treatment capacity immediately because existing maximum day demands exceed plant capacity. The areas adjacent to the existing plant are fully developed with residential and commercial buildings, so it is recommended that the new plant be built south of East Grand Forks and east of Grand Forks as indicated on figure 34.



EXISTING	IMMEDIATE NEEDS (BY 2000)	LONG-RANGE NEEDS (BY 2030)	LEGEND
■	□	⬚	TREATMENT PLANT
●	○	◌	INTAKE AND PUMPS
▲	△	△	LOW HEAD DAM
———	– – – –	········	PIPELINES

NOTES:

1. TABLE 41 LISTS THE SCHEDULING OF PROPOSED IMPROVEMENTS.
2. SELF-SUPPLIED INDUSTRIES AND RURAL WATER DISTRICTS WILL CONTINUE TO SUPPLY THEIR NEEDS SEPARATELY.

Figure 34 - Recommended Plan

Each water service agency should consider water conservation programs. The water conservation programs outlined previously can reduce maximum day water use by about 10 percent and average day demands by about 8 percent. These reductions would result in a cost savings of about $300,000 per year in equivalent annual costs. Costs for implementing water conservation practices and resulting cost savings should be assessed in more detailed studies conducted by the local water service agencies and based on the programs implemented.

Improvements for the self-supplied industries and rural water districts are not included in table 41. It is recommended that these entities expand their facilities to satisfy their existing and projected demands as the capacity of their facilities is exceeded.

The costs presented in table 41 are those developed during the evaluation of the alternatives. While these costs are intended to be as realistic as possible, they were developed for comparative purposes from cost curves and are based on many assumptions. As more detailed studies are completed, the costs and implementation schedule can be adjusted.

Table 41 - Implementation schedule and recommended plan

Year	Item	Cost ($)	Notes(1)
Grand Forks			
1980	O&M Supply	23,000	For existing 7.7 mgd flow. Uniform to 2005.
1980	O&M Treatment	1,360,000	For existing 7.7 mgd flow. Uniform to 2005.
1985	Capital Cost	170,000	Refurbish GF #3 supply.
1990	Capital Cost	80,000	Refurbish GF #1 supply.
		4,970,000	Refurbish existing 12 mgd treatment plant.
2005	Abandon Facilities	0	GF #1, 2, and 3 supply and existing 12 mgd treatment plant. No salvage value.
East Grand Forks			
1980	O&M Supply	5,000	For existing 1.5 mgd flow. Increases linearly to 2005 value.
1980	O&M Treatment	427,000	For existing 1.5 mgd flow. Increases linearly to 2005 value.
1990	Capital Cost	3,120,000	Refurbish existing 4 mgd treatment plant.
2005	O&M Supply	6,000	For 2.1 mgd flow.
2005	O&M Treatment	514,000	For 2.1 mgd flow.
2005	Abandon Facilities	0	Supply and existing 4 mgd treatment plant. No salvage value.
Combined Facilities			
1980	Capital Cost	9,670,000	New 6 mgd treatment plant and land.
		3,880,000	New supply for 6 mgd pumping and 20 mgd structural.
1980	O&M Supply	5,000	For 0 mgd flow. Increases linearly to 2005 value.
1980	O&M Treatment	0	For 0 mgd flow. Increases linearly to 2005 value.
1985	O&M Storage	20,000	Maintain RRN low head dam.
		20,000	Maintain RLR low head dam.
1990	Capital Cost	2,510,000	Replace RRN low head dam.
		3,140,000	Replace RLR low head dam.
1990	O&M Storage	20,000	Maintain RRN low head dam in eight 5-year intervals to 2030.
		20,000	Maintain RLR low head dam in eight 5-year intervals to 2030.
2005	O&M Supply	12,000	For 2.6 mgd flow.
2005	O&M Treatment	674,000	For 2.6 mgd flow.
2005	Relocation of GF/EGF Supply/Treatment to new site		
2005	Capital Cost	1,160,000	Expand supply to 30 mgd (pumping only).
		31,300,000	New 30 mgd treatment plant.
2005	O&M Supply	37,000	For 12.4 mgd flow. Increases linearly to 2030 value.
2005	O&M Treatment	2,150,000	For 12.4 mgd flow. Increases linearly to 2030 value.
2030	O&M Supply	46,000	For 16.7 mgd flow.
2030	O&M Treatment	2,800,000	For 16.7 mgd flow.
2030	Salvage	1,770,000	Low head dams, supply, land.
Grand Forks Air Force Base			
1980	Capital Cost	6,290,000	For supply, 15.5 miles of 15" pipe from GF to base.
1980	O&M Supply	19,000	Existing 16" and new 15" pipe Uniform 402030.
Equivalent Annual Cost		4,560,000	

Notes: (1) Components of supply are intake structures and water transmission lines.
RRN - Red River of the North
RLR - Red Lake River
Unless otherwise stated, O&M costs are assumed to be applied annually.

Source: Stanley Consultants, Inc.

DROUGHT ACTION PLAN

GENERAL

The drought action plan should be implemented when available sources of water supply can no longer satisfy local water needs in the Grand Forks-East Grand Forks urban area. It outlines the procedures which should be followed in response to drought conditions and includes:

1. A step-by-step procedure to be implemented as the available water supplies dwindle.
2. A review of governmental agencies which can provide assistance during droughts.

The plan briefly reviews water conservation practices, the status of the Garrison Diversion project, and other alternative water supply sources.

DROUGHT POTENTIAL

Drought is an extended period of dry weather which may have severe effects on the capability of a water supply to fulfill the water needs of an urban area. The GF/EGF urban area has experienced drought in the past. In the 1930's, Red River of the North and Red Lake River flows were so low that many of the cities, industries, and other users experienced serious difficulties in supplying their basic needs.[1] Severe droughts have occurred in the 1910's, 1930's, 1950's, and 1970's, and less severe droughts have occurred in the 1920's, 1940's, and 1960's.[26] In 1976 and 1977, the area experienced severe drought conditions that reduced the flows in the Red River of the North to a small fraction of their

mean.[5] Fortunately, releases from the Red Lakes Reservoirs kept the Red Lake River flows high.

The average annual precipitation at Grand Forks for the 69 years of record ending in 1966 was 20.02 inches; however, as little as 9.4 inches has fallen in a single year.[2] Evaporation losses increase during hot, dry periods associated with drought conditions. Also, growth in the river basin and the GF/EGF urban area has increased water demands.

Since the sources of water supply in the urban area are the Red River of the North and Red Lake River, extended drought conditions pose a serious threat to the urban areas. Severe droughts can require restricted use of water or water rationing. These measures would affect the economy and well-being of the urban area. The water utilities, local governments, and all water users should understand actions that may be implemented to mitigate the effects of dwindling water supplies.

WATER CONSERVATION

Water conservation is an important and necessary part of a drought action plan. Water use must be reduced to conserve available water supplies.

Table 42 summarizes the potential water savings of various water conservation programs during nondrought periods. Water conservation during nondrought periods reduces peak demands and total water use. Thus, existing water supplies, treatment facilities, and distribution systems are more efficiently used. During drought situations, the primary purpose of water conservation is to reduce the total water use.

Table 42 indicates that water conservation practices can reduce total water use as much as 10 to 15 percent during nondrought conditions. However, greater savings can be expected, at least temporarily, during severe drought emergencies as the

Table 42 - Summary of estimated water savings by various water conservation programs

Program	Estimated Savings (percent)	Remarks
Public education including bill inserts, newsletters, pamphlets, workshops, and media announcements.	1 1/2 to 5	Building blocks for any successful water saving measures.
Public education and installation of water saving devices (retrofit).	4 to 7 1/2	Reduces total water use.
Public education, retrofit, and a rate change including a surcharge for excess use.	8	Reduces total water use and the peak to average day demand ratio.
Public education, mandatory retrofit, plumbing code change, lawn irrigation ordinance, and modification of rate structure with excess use surcharge.	10 to 15	Reduces total water use and the peak average day demand ratio.

Source: Reference 43, 44, and Stanley Consultants

general public responds to the emergency. Water conservation programs would be intensified during drought conditions as programs for public awareness, leak repair, retrofitting of existing homes and buildings, and regulation of water use are implemented.

Water conservation practices are more easily implemented during drought emergencies. However, many of these practices can result in long-term water demand reduction. Long-term effects would result from the installation of toilet displacement dams and shower head orifices. Ordinances controlling lawn irrigation,

requiring water saving appliances in new homes, and raising water rates will also result in long-term reductions in water use. Commercial and industrial water use reduction practices which are implemented during drought emergencies may continue after the emergency has ended.

GARRISON DIVERSION PROJECT

The Water and Power Resources Service's Garrison Diversion project would divert water from the Missouri River to other river basins including the Red River of the North. This diverted water would be used to satisfy agricultural irrigation, municipal/industrial, fish and wildlife management, and recreational water demands.

As discussed earlier, serious political and environmental constraints have stopped the completion of this project. Therefore, the Garrison Diversion project cannot be relied on at the present time to satisfy water demands during normal and/or drought conditions. There is a possibility that political and environmental constraints can be overcome and the project reactivated and completed. However, based upon discussions with Water and Power Resource Service's personnel, it appears that this is unlikely in the near future. Also, before water could be diverted to the Red River of the North basin under *normal operation*, several major construction projects must be completed. These projects include part of the Lonetree Reservoir, a sand filter at Lonetree Dam, and removal of a plug in McClusky Canal for which funding is being requested. The request for continued funding is being reviewed by the Secretary of the Interior but funding is not likely until all political and environmental constraints are overcome.[34,35]

ALTERNATIVE SOURCES OF WATER SUPPLY

The number of alternative sources of water supply in the GF/EGF area is limited. There are no lakes, reservoirs, or other

water impoundments that can be used. During droughts, the various coulees, oxbows, and other depressions would be dry. The wastewater treatment lagoons would be a source of nonpotable water, such as for irrigation, as long as applicable rules and application rates are followed. According to the Minnesota Department of Health, wastewater reuse as a potable source is not an acceptable alternative at this time. In summary, there are no alternative surface water sources which could be used during drought emergencies.

The availability and acceptability of groundwater sources are limited. The Grand Forks aquifer which is located below Grand Forks has poor water quality and would not be potable without extensive treatment. Groundwater which accumulates in rock quarries and other excavations could be a source of nonpotable water for livestock and irrigation. The Elk Valley aquifer in western Grand Forks County and the Beach Ridge aquifers in central Polk County are potential sources of relatively good quality water. However, a large number of wells would be required to tap these sources, and the relatively long distances from the GF/EGF urban area would make transportation of these waters expensive. During severe and extreme drought conditions, the Elk Valley aquifer could be a viable source of potable water. This water would probably be trucked to the urban area.

DROUGHT EMERGENCY RESPONSE

When a drought emergency occurs or is forecast, the drought action plan should be implemented. The local governments and particularly the mayor and city council of each municipality and the governing boards of other local governmental entities have ultimate responsibility for implementing the plan. However, the drought action team which assesses the situation, makes recommendations, and implements local efforts includes the city

council, water utility personnel, director of public works, city engineers, chambers of commerce, and other interested groups. To ensure maximum effectiveness from the plan, residential, commercial, and industrial users must cooperate. Emergency services agencies at the local, regional, State, and Federal levels can provide valuable assistance to local goverments after all possible local efforts have been undertaken.

The drought action plan includes two major parts as follows:

1. Water demand reduction plan.
2. Agency assistance and responsibilities at local, regional, State, and Federal levels.

These two parts are outlined in detail in the following sections.

WATER DEMAND REDUCTION PLAN

The most readily available and perhaps the most acceptable approach for surviving a drought emergency is to reduce total water use (demand). A water demand reduction plan is outlined below. The plan is staged to respond to increasingly severe drought conditions. Each stage involves further reduction in total water use. The most important aspect of this plan should be the maintenance of the public health and well being of the general populace. Thus, the basic needs of residential users should have priority over commercial, industrial, and irrigation needs.

The water demand reduction plan involves five stages. The first two stages basically include voluntary measures to reduce the total water demand and to alert the public that drought conditions may continue to become more severe. Only minor (although significant) water reduction can be expected through voluntary methods. During more severe droughts, local governments would enforce mandatory water reduction measures presented in the last three stages. Policing of these mandatory measures would be through public support, direct monitoring of water meter readings,

and inspection of water-using facilities. A pricing system that penalizes excess water use should be implemented as an incentive to reduce use.

The schedule for implementing this plan depends upon the available quantity of water. The constraints that limit the quantity include river flow, storage volume, intake capabilities, pumping capacities, and transmission capacities. River flows are the most important constraint; however, if a pumping station is out of service the quantity of water may be limited by this factor.

The low-flow frequency analysis indicates that natural streamflows supplemented by existing in-channel storage can satisfy most urban area water demands. The natural streamflows are augmented during dry periods by releases from the Red Lakes Reservoir. The low-head dams in the urban area pool water on the Red River of the North and the Red Lake River. Grand Forks has two intakes on the Red River of the North. The Red Lake River serves the East Grand Forks intake, one Grand Forks intake, and the self-supplied industries intakes. It has been recommended that East Grand Forks construct a water intake on the Red River of the North to increase the reliability of its water supply.

The combined Red River of the North and Red Lake River flows and in-channel storage can satisfy urban area water demands for droughts up to at least 100-year return frequency. Therefore, the water demand reduction plan would be implemented on the average less than once every 100 years to offset water supply shortages. If East Grand Forks uses only the Red Lake River as its water supply source, the water demand reduction plan would have to be implemented during low flows that recur on the average once every 50 to 60 years. The low-flow frequency analysis indicates that the Red Lake River natural streamflow plus in-channel storage

can satisfy East Grand Forks and the self-supplied industries water demand through a drought that has a recurrence interval of once every 50 years.

If some part of the water intake, pumping, transmission, and/or treatment systems is out-of-service and the water demands cannot be satisfied, the water demand reduction plan should be implemented accordingly.

If the low-head dams are lost and water is not pooled in- and/or off-channel, water shortages will also occur. Without supplemental storage, the streamflows must be able to satisfy the maximum day rather than average day demands. The low-flow frequency analysis calculated the average streamflow for various durations. Based on the average 7-day flow of the combined Red River of the North and Red Lake River serving the GF/EGF urban area water demands, the stages of the water demand reduction plan must be implemented as frequently as follows:

	% Water Demand Reduction	Implemented Every "x" Years: Based on 1980 Water Demands	Based on 2030 Water Demands
Maximum Day Demand		24.8 cfs	44.6 cfs
Stage A	--	100	5
Stage B	10	> 200	6
Stage C	30	> 200	16
Stage D	50	> 200	> 200
Stage F	70	> 200	> 200

Based on the low-flow frequency analysis and the Red Lake River serving just East Grand Forks, the water demand reduction plan would be implemented as frequently as follows:

	% Water Demand Reduction	Implemented Every "x" Years Based on 1980 Water Demands	Based on 2030 Water Demands
Maximum Day Demand		4.3 cfs	8.2 cfs
Stage A	--	15 to 20	1 to 2
Stage B	10	15 to 20	1 to 2
Stage C	30	35	15 to 20
Stage D	50	> 200	20
Stage F	70	> 200	200

The above summaries emphasize the importance of maintaining and replacing the urban area low-head dams on the Red River of the North and the Red Lake River.

The USGS Gaging Station Number 05082500 at Grand Forks will provide the most accurate information on the quantity of water in the combined Red River of the North and Red Lake River flows. This information should be supplemented by gages at each water intake and gages upstream of the GF/EGF urban area. The 1972 report entitled Souris-Red-Rainy River Basins Comprehensive Study indicates that the minimum flow which must be allowed to pass the GF/EGF urban area is 8 cfs (cubic feet per second). This quantity of water includes prior water rights of downstream water users.

The five stages of the water demand reduction plan are outlined below. The "steps to be implemented" in each stage were adopted with modifications from the Washington Suburban Sanitary District ordinance entitled "Water Demand Reduction Plan."[63]

Stage A - Water Shortage Alert

This stage would be implemented as follows:

1. Without in- and/or off-channel storage and when river flows are equal to or less than 100 percent of the GF/EGF urban area water demands plus the desired downstream flow of 8 cfs or when the water intake, pumping, transmission, and/or treatment systems cannot satisfy all water demands.

2. With in- and/or off-channel storage and when the projected river flows and in- and/or off-channel storage are not capable of supplying two times the GF/EGF urban area water demands plus the desired downstream flow of 8 cfs for the next 6 months, or when the water intake, pumping, transmission, and/or treatment systems cannot satisfy all water demands.

The steps to be implemented are:

1. Notify local governmental officials, water utility personnel, other city personnel, local coordinators of emergency services, and the public of the Alert condition.
2. Increase maintenance of intake structures, raw water pumping stations, and other facilities, as appropriate.
3. Increase monitoring of treated water demand.
4. Increase use of weather forecast and soil moisture deficit data. Contact Corps of Engineers for weather information and forecasts and limited streamflow data.
5. Publicize limitations of physical water systems if the limitations affect the water supply situation, for example, high service pumping breakdowns.
6. Through the preestablished notification procedures request that local, State, and Federal agencies, commercial and industrial users, supporting chambers of commerce, and other local supporting groups take the following actions:
   a. Check for system leaks by shutting off automatic water makeup on chilled water systems and hot water boiler heating systems.
   b. Ensure that cooling tower controls and operations are properly calibrated and maintained to prevent excess water use and overflow on shutdown.
   c. Establish daily water meter reading programs to identify leaks.
   d. Inspect total plumbing system to ensure watertight conditions of faucets, valves, unions, etc.

Stage B - Water Shortage Restriction

This stage involves voluntary compliance to reduce water demand up to 10 percent and would be implemented as follows:

1. Without in- and/or off-channel storage and when the river flows are between 90 and 100 percent of the GF/EGF urban area water demands plus the desired downstream flow of 8 cfs, or when the water intake, pumping, transmission and/or treatment systems can only satisfy between 90 and 100 percent of all water demands.

2. With in- and/or off-channel storage and when the projected river flows and in- and/or off-channel storage are not capable of supplying one and one-half times the GF/EGF urban area water demands plus the desired downstream flow of 8 cfs for the next 3 months or when the water intake, pumping, transmission, and/or treatment systems can satisfy only 90 to 100 percent of all water demands.

The steps to be implemented are:

1. Implement all steps in Stage A with the following modifications and additions.

2. Notify local governmental officials, water utility personnel, other city personnel, local coordinators of emergency services, and the public of the Restriction condition.

3. Request residents to limit water consumption by installing toilet displacement dams and shower head flow restricting devices, reducing lawn irrigation, and reducing car washing. The goal should be to reduce water use to an average 90 gallons per person per day.

4. Intensive public awareness and education campaign.

5. Through the preestablished notification procedures request that local, State, and Federal agencies, residential users, commercial and industrial users, supporting chambers of commerce, and other supporting groups take the following actions:

    a. Adjust automatic and/or controlled landscape watering systems to avoid runoff; confine lawn watering and sprinkling to every other day and between the hours of 10 p.m. and 6 a.m. with the exception of commercial florists, nurseries, and agricultural use and facilities with certified private or separate sources of water such as private ponds, lakes, or wells.

    b. Restrict car washing to a bucket and sponge method.

c. Discontinue operation of all ornamental fountains, waterfalls, reflecting ponds, and similar amenities.

d. Request general conservation of inside water use by:

   (1) Retrofitting tank type toilets with displacement dams or plastic bottles filled with gravel or by bending the float rod down to reduce fill level by one-fourth.

   (2) Installing flow reduction orifices in shower heads.

   (3) Loading dishwashers to maximum capacity.

   (4) Using minimum amount of water for washing vegetables, fruits, and other produce.

   (5) Reducing water pressure to all sinks by partially closing valves on water lines.

   (6) Reducing the flow of water on all stop valve urinals and commodes.

   (7) Serving water to restaurant customers on request only.

   (8) Closing down main water valve serving each user to reduce pressure.

e. Provide self-closing nozzle valves on all hoses.

f. Restrict filling or refilling of swimming or wading pools, except for makeup.

g. Load washing machines to maximum capacity. Businesses such as, but not limited to, beauty salons, barber shops, and car washes that wash linens in on-premise washing machines are to load to maximum capacity and use the minimum wash cycle.

h. Prohibit the use of water from fire hydrants for any purpose other than fire extinguishing or water interconnection, except for essential static or residual fire plan tests.

i. Discontinue washing exteriors of vehicles except where 50 percent or more of the water is recycled or buckets not exceeding 3-gallon capacity are used for all businesses such as, but not limited to, automobile rental and sales, filling stations, taxi companies, trucking facilities, and commercial garages.

<u>Stage C - Water Shortage Emergency</u>

This stage includes mandatory compliance to reduce water demand between 10 and 40 percent and would be implemented as follows:

1. Without in- and/or off-channel storage and when the river flows are between 60 and 90 percent of the GF/EGF urban area water demands plus the desired downstream flow of 8 cfs, or when the water intake, pumping, transmission, and/or treatment systems can satisfy only 60 to 90 percent of all water demands.

2. With in- and/or off-channel storage and when the projected river flows and in- and/or off-channel storage are not capable of supplying 100 percent of the GF/EGF urban area water demands plus the desired downstream flow of 8 cfs for the next 30 days, or when the water intake, pumping, transmission, and/or treatment systems can satisfy only 60 to 90 percent of all water demands.

The steps to be implemented are:

1. Implement all steps in Stages A and B with the following modifications and additions.

2. Notify local governmental officials, water utility personnel, other city personnel, local coordinators of emergency services, and the public of the Emergency condition.

3. Limit residential water consumption to a maximum 75 gallons per person per day (one bath, one flush per person per day, one laundry per family every other day).

4. Implement pricing system that discourages excess use.

5. Restrict all commercial, industrial, and governmental water use in the following ways:

   a. Industrial, commercial, retail, and office buildings:

      Buildings with cooling towers to raise building temperatures to 78° and/or raise chill water temperature to achieve 78° temperature. Do not start up air conditioning system for the day until inside temperature reaches or exceeds 78° and shut down system one-half hour before closing. Food facilities that require cooling for food storage and preservation are excepted.

   b. Restaurants, drive-ins, and fast-food facilities:

      (1) Use paper service in lieu of china and glassware.

      (2) Serve only half glasses of water and only on request.

(3) Turn off all water not used in food or drink preparation.

(4) Discontinue use of garbage disposal.

(5) Reduce floor washing in customer area; sweep, damp mop, and disinfect only.

c. Restrooms:

(1) Shut off hot water to public restrooms and reduce cold water pressure to bare minimum.

(2) Reduce hot and cold water pressure to employee restrooms to bare minimum.

(3) Lower hot water temperature to 100° (except in food facilities).

(4) Close all except one men's and one women's restroom in stores where there is more than one set of restrooms.

(5) Install "Water Shortage - Please Conserve" signs.

d. Department and retail stores:

(1) In addition to Sections 1 and 5a, b, and c, permanently turn off all water valves located on exterior of building by closing stop valves located inside building or replacing exterior valve with pipe plug.

(2) When possible, reduce pressure on main water service entering building.

(3) Permanently close one-half of the beauty salon sinks and secure towel washing machine.

(4) Disconnect all customer drinking fountains.

e. Hotels, motels, inns, and boarding houses:

(1) Implement all parts of Sections 1 and 5a, b, c, and d.

(2) Change bed linen every other day when occupants stay more than one day.

(3) Disconnect all public convenience ice cube-making machines.

(4) Instruct maids to use only buckets for bathroom cleaning.

(5) Post water conservation signs at each point of water use in individual rooms as well as public areas.

f. Health care facilities including hospitals, clinics, sanitariums, nursing homes, pharmacies, laboratories, ambulance services, and rescue squads: Implement only those parts of Sections 1 and 5a, b, c, d, and e which do not endanger intended services.

g. Dentists and doctors:

   (1) Implement Sections 1 and 5a, b, c, d, e, and f.

   (2) Turn off all continuously running water devices.

h. Universities and colleges:

   (1) Implement all parts of Sections 1 and 5a, b, c, d, and e, as applicable.

   (2) Close laundry rooms between 11 a.m. and 7 p.m.

i. Private clubs, public parks, golf courses, country clubs, and other recreational facilities: Implement all parts of Sections 1 and 5a, b, c, d, and e.

j. Landscape and lawn watering: Eliminate all lawn watering and sprinkling except commercial florists, nurseries, and agricultural use and facilities with certified private or separate sources of water.

6. Assess the need for and prepare applications for State and/or Federal aid including an emergency water release from Corps of Engineers reservoirs. Contact State emergency service agencies.

7. Designate and authorize local inspectors to enforce restrictions. Local police may be used to supplement and/or enforce restrictions. Each inspector should carry proper identification.

Stage D - Severe Water Shortage Emergency

This stage involves mandatory compliance to reduce water demand between 40 and 60 percent and would be implemented as follows:

1. Without in- and/or off-channel storage and when the river flows are between 40 and 60 percent of the GF/EGF urban area water demands plus the desired downstream flood of 8 cfs, or when the water intake, pumping, transmission, and/or treatment systems can satisfy only 40 to 60 percent of all water demands.

2. With in- and/or off-channel storage and when the projected river flows and in- and/or off-channel storage are capable of supplying only 40 to 60 percent of the GF-EGF urban area water demands plus the desired downstream flow of 8 cfs, or when the water intake, pumping, transmission, and/or treatment systems can satisfy only 40 to 60 percent of all water demands. The storage volume would be essentially zero.

The steps to be implemented are:

1. Implement all steps of Stages A, B, and C, with the following modifications and additions.

2. Limit residential consumption to 40 gallons per person per day (one bath, one flush per person per day, hand wash only essential laundry).

3. Negotiate for use of water from private/independent sources to maintain a reserve for fire purposes.

4. Restrict all commercial, industrial, and governmental water use in the following ways:

   a. Industrial, commercial, retail, and office buildings: Buildings with cooling towers to raise building temperature to 80° and/or raise chill water temperature to achieve 80° temperature, plus close all bleed-off valves. Where multiple units are used, cut off one air conditioner unit. Food facilities that require cooling for food storage and preservation are excepted. Manufactured products, computer rooms, laboratory and research equipment that are similarly heat-sensitive are excepted.

   b. Restaurants, drive-ins, and fast-food facilities:

      (1) Serve no water to customers.

      (2) Reduce and/or eliminate use of steamers for food warming.

      (3) Turn off ice cream dipper fountains.

      (4) Discontinue use of ice cubes.

      (5) Evaluate additional conservation measures.

   c. Restrooms:

      (1) Shut off cold water to all public restroom sinks.

      (2) Restrict urinals and toilets to minimal water flow.

d. Department and retail stores:

(1) Implement all parts of Sections 1 and 4a, b, and c.

(2) Permanently turn off steam boiler used only for alterations; use steam irons.

(3) Beauty and barber shops shampoo with single rinse only; use spray bottles instead of sink to wet hair for hair cuts; use disposable paper towels, or have linens and towels washed by commercial laundry located outside the area affected by the drought, when possible.

(4) Reduce interior heat loads in summer by turning off as many lighting fixtures as possible.

e. Hotels, motels, inns, and boarding houses:

(1) Implement all parts of Sections 1 and 4a, b, c, and d.

(2) Change bed linens every third day where occupants stay more than two days.

(3) Provide only one set of towel and wash cloth linen per occupant per day.

(4) All linens and towels to be washed by commercial laundry located outside the area affected by the drought, when possible.

(5) Discontinue use of ice cubes except for food preparation.

f. Commercial laundries: Reduce water consumption by at least 30 percent.

g. Bottling plants:

(1) Discontinue washing and refilling returnable bottles.

(2) Reduce water consumption by at least 40 percent.

(3) Wherever possible, use trucked-in water for all washing and bottling needs.

h. Landscape and lawn watering: Discontinue outside watering and sprinkling.

5. Prohibit washing of sidewalks and exterior paved areas, vehicles, building windows, and other nonessential items.

6. Designate and authorize local inspectors to enforce restrictions. Local police may be used to supplement and/or enforce restrictions. Each inspector should carry proper identification.

Stage F - Extreme Water Shortage Emergency

This stage involves mandatory compliance to reduce water demand by more than 60 percent and would be implemented as follows:

1. Without in- and/or off-channel storage and when the river flows are less than 40 percent of the GF/EGF urban area water demands plus the desired downstream flow of 8 cfs, or when the water intake, pumping, transmission, and/or treatment systems can satisfy less than 40 percent of all water demands.

2. With in- and/or off-channel storage and when the projected river flows and in- and/or off-channel storage are not capable of supplying 40 percent of the GF/EGF urban area water demands plus the desired downstream flow of 8 cfs, or when the water intake, pumping, transmission, and/or treatment systems can satisfy less than 40 percent of all water demands. The storage volume would be zero.

The steps to be followed are:

1. Implement all steps of Stages A, B, C, and D, with the following modifications and additions.

2. Limit residential consumption to 30 gallons per person per day (one flush per person per day, one bath per person every other day, hand wash only essential laundry).

3. Implement previously negotiated use of all lakes, wells, and other private water supplies, such as quarries and the Elk Valley aquifer, for use as potable water supply.

4. Establish emergency water supply points with water tank trucks or trailers to provide minimum essential supplies of potable water to residents for human consumption at a rate of one-half gallon per person per day.

5. Establish water purification points on available water sources (for example, lakes and quarries) and/or arrange with nonaffected water suppliers for refilling water transport vehicles used to provide potable water to emergency water supply points.

6. Prepare for fire suppression operations utilizing the following:

   a. Available "tank wagons."

   b. Tank wagons obtained under mutual aid agreements with nonaffected jurisdictions.

   c. Water transport vehicles from emergency water supply points.

   d. Fire department water resupply points identified in advance and established by local fire departments at streams, ponds, or other water sources.

   e. Water resupply points established to refill water transport vehicles from emergency water supply points.

7. Prescribe hygienic measures for human waste disposal in recognition that a water outage precludes flushing of public toilets. Use local health and environmental agencies to determine specific measures for the particular situation including the following:

   a. Use of nonpotable water such as rainwater or streams and ponds for toilet flushing.

   b. Use of expedient toilets made with garbage cans or similar containers partially filled with water/bleach mixture sufficient to cover waste material (1/2 cup of household laundry bleach per gallon of water).

   c. Use of outside "slit" trenches with lime to cover waste material.

   d. Use of commercial chemical toilets at public locations, such as near emergency water supply points.

8. Restrict all commercial, industrial, and governmental water use in the following ways:

   a. Turn off all water-cooled air conditioning units not excluded in previous stages.

   b. Turn off and secure water supplies to all sinks and 65 percent of all machines in launderettes or laundromats.

   c. Use only water trucked in from sources outside the area affected by the drought for concrete batching plants and other manufacturing plants using water as a base for their product.

9. Designate and authorize local inspectors to enforce restrictions. Local police may be used to supplement and/or enforce restrictions. Each inspector should carry proper identification.

AGENCY ASSISTANCE AND RESPONSIBILITIES

Local, regional, State, and Federal agencies can respond to a drought emergency and provide assistance to the local governments. This assistance includes:

1. General information such as weather forecasts, streamflow data, and reservoir operation.
2. Technical and financial aid such as procedures, manpower, supplies, equipment, and funds.

Before outside assistance can be obtained, local governments must use all possible local resources to combat the drought. Mayors have ultimate responsibility for directing the drought action plan. However, in Grand Forks, the mayor may appoint a qualified local official to direct the plan. As local water supplies dwindle, local governments should undertake the following actions:

1. Monitor weather forecasts, streamflows, and reservoir operation. This information should be obtained through the Corps of Engineers.
2. Implement the "Water Demand Reduction Plan" and commit all possible local resources including funds, manpower, and equipment.
3. Contact local emergency services coordinators.
4. Declare a drought emergency.

As the drought condition becomes more severe and local capabilities are exceeded, outside assistance should be obtained. This assistance should be requested at the same time Stage C of the "Water Demand Reduction Plan" is implemented. Requests for technical and financial aid from State and Federal agencies must be handled through the local emergency services coordinators:

1. Grand Forks County Disaster Emergency Services.

2. East Grand Forks and Polk County Emergency Services.

These coordinators should be kept informed of the problems which occur as the drought condition becomes more severe, so they can relay this information to the State and Federal coordinators when assistance is requested. Before State and Federal aid can be requested, local governments must declare a drought emergency or disaster. Then local governments should follow the procedures already developed by North Dakota and Minnesota emergency services agencies.

Figure 35 graphically displays the steps which would be taken as a drought becomes more severe. Figure 35 also indicates the agency (and person, when available) that should be contacted.

The local, regional, State, and Federal emergency service agencies play an important role during a drought. These agencies assess the drought conditions, coordinate outside efforts, and provide technical and financial assistance. The responsibilities and assistance provided by the emergency service agencies and other agencies are outlined below.

The North Dakota Disaster Emergency Services includes county and State offices which, as a team, assist local governments during drought emergencies. The State office becomes involved when the emergency exceeds the local coordinators' capabilities. The county and State offices should be primary advisors to local governments concerning drought conditions and procedures for initiating the drought action plan. The assistance they provide includes the following:

1. Advise local governments on procedures, available relief services, and other sources of aid.
2. Assess the drought condition and recommend appropriate action.

3. Administer disaster response and recovery programs under Public Law 93-288 (Federal Disaster Relief Act of 1974).
4. Advise and make recommendations to the Governor that he:
   a. Petition the Corps of Engineers to make emergency releases from its reservoirs.
   b. Request involvement of State agencies and obtain their assistance as needed. These include, but are not limited to, the following:
      State Water Commission
      Department of Health
      National Guard
   c. Appoint an "on-site" coordinator and assessment team composed of representatives from various State agencies. This team assesses drought conditions and directs use of State resources.
   d. Request a Presidential declaration of a major disaster or an emergency when the drought condition becomes severe enough, so the Federal Emergency Management Agency (FEMA) can become involved.
   e. Prepare to promote legislation which may be needed to mitigate drought conditions.
5. Coordinate the assistance provided by State and Federal agencies directly to the affected area such as manpower, supplies, equipment, and technical assistance.
6. Implement the procedures outlined in the North Dakota: Disaster Procedure Handbook I[65] and North Dakota: Disaster Plan.[66]

The North Dakota State Water Commission is responsible for managing the State's waters and administering State policies

3. Administer disaster response and recovery programs under Public Law 93-288 (Federal Disaster Relief Act of 1974).
4. Advise and make recommendations to the Governor that he:
    a. Petition the Corps of Engineers to make emergency releases from its reservoirs.
    b. Request involvement of State agencies and obtain their assistance as needed. These include, but are not limited to, the following:
        State Water Commission
        Department of Health
        National Guard
    c. Appoint an "on-site" coordinator and assessment team composed of representatives from various State agencies. This team assesses drought conditions and directs use of State resources.
    d. Request a Presidential declaration of a major disaster or an emergency when the drought condition becomes severe enough, so the Federal Emergency Management Agency (FEMA) can become involved.
    e. Prepare to promote legislation which may be needed to mitigate drought conditions.
5. Coordinate the assistance provided by State and Federal agencies directly to the affected area such as manpower, supplies, equipment, and technical assistance.
6. Implement the procedures outlined in the North Dakota: Disaster Procedure Handbook I [65] and North Dakota: Disaster Plan. [66]

The North Dakota State Water Commission is responsible for managing the State's waters and administering State policies

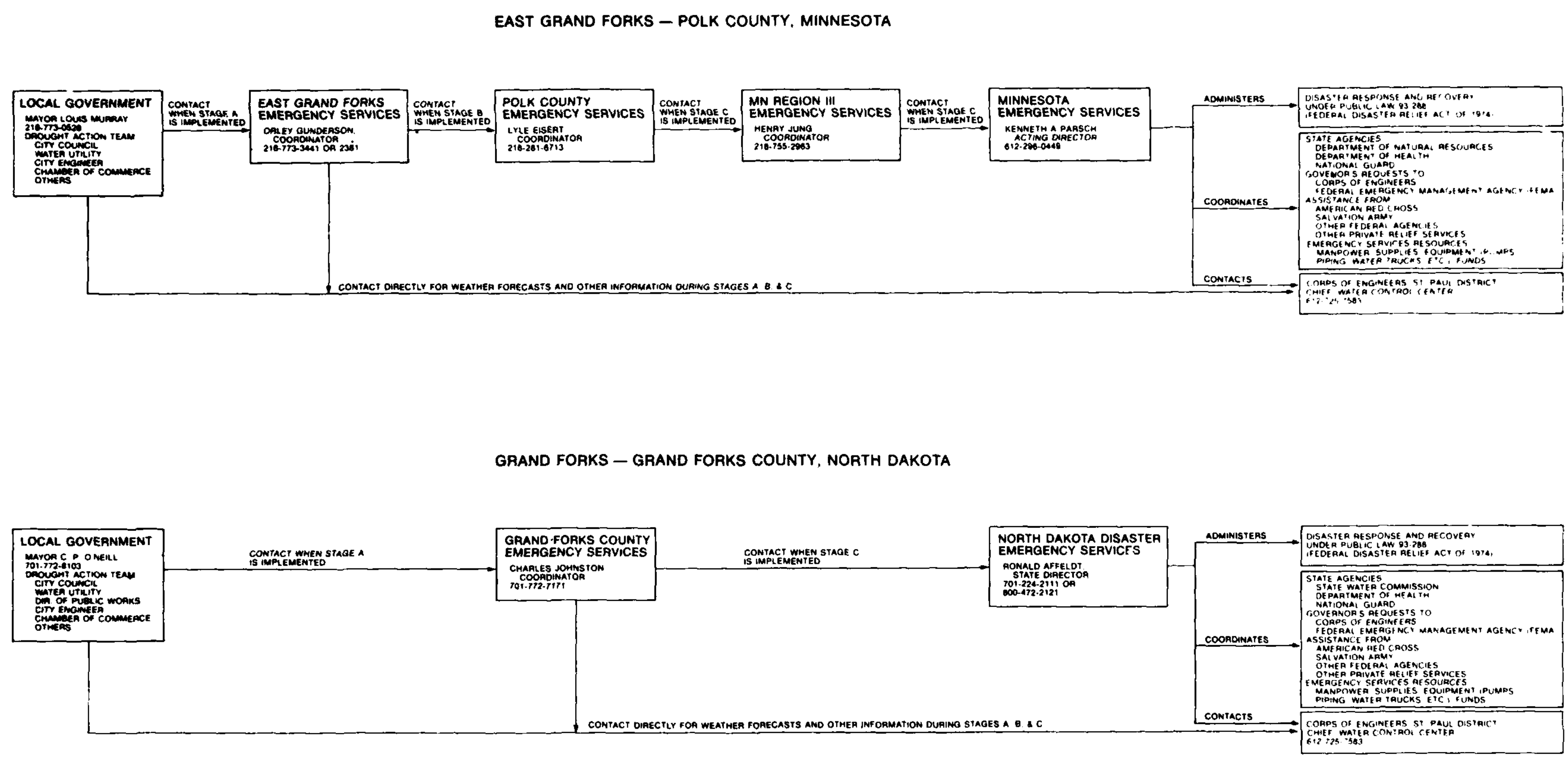


Figure 35 -
Drought Action Organization Chart

which allocate water on the basis of a permit system. This permit system allocates water to the earliest dated permit first.

The Minnesota Emergency Services includes local, county, regional, and State offices which, as a team, assist local governments during drought emergencies. The next higher level office becomes involved as the preceding office's capabilities are exceeded. MES should be a primary advisor to local governments concerning drought conditions and procedures for mitigating the drought. MES assistance is similar to that provided by the North Dakota Disaster Emergency Services. However, State financial aid is available through application to the State Executive Council. The regional director of emergency services is responsible for directing State resources in the affected area. MES procedures are outlined in the Minnesota Disaster Emergency Plan.[67]

In Minnesota, the Department of Natural Resources is responsible for the waters of the State and provides the same services as the North Dakota State Water Commission. Minnesota retains control of State waters and allocates the use of these waters on the basis of an established priority system. In this system, residential water needs have first priority.

The North Dakota and Minnesota Departments of Health have jurisdiction over municipal and public drinking water supplies and waste disposal systems. These agencies can provide assistance for determining treatment requirements for potential sources of water supply.

The North Dakota and Minnesota National Guards can obtain, transport, and distribute potable water during extreme drought conditions. The National Guard could also assist in inspection efforts required by the "Water Demand Reduction Plan."

The Corps of Engineers plays a major role in combating droughts in the urban area. The Corps can provide general information obtained from other Federal agencies. This

information includes weather forecasts, streamflow data, reservoir operation, and reservoir levels. The Corps obtains this information from the National Weather Service, the USGS, and other Corps branches. This information can also be obtained directly by the local governments through the individual agencies. Other assistance provided by the Corps must be coordinated through the emergency services agencies and the Governors of the two States. This assistance might include "providing emergency releases" of water from the reservoirs upstream of the GF/EGF urban area including Red Lakes, Orwell Lake, Lake Traverse, Lake Ashtabula, and the authorized Twin Valley and Kindred Lakes. Releases from the Red Lakes are controlled through a treaty with the Chippewa Indians. The authorized lakes are in various planning stages, so they will not be constructed for several years.

FEMA is the primary Federal agency responsible for mitigating major disaster and emergency conditions. It coordinates and directs all Federal assistance and advises local governments on the availability of Federal programs, assistance, and financial aid. Its assistance is provided through regional offices. North Dakota is served by Region 8, headquartered in Denver, Colorado. Minnesota is served by Region 8, headquartered in Chicago, Illinois. FEMA becomes involved after State government capabilities have been exceeded. The Governor requests a presidential declaration of a major disaster or emergency through the FEMA regional office. The national administrator assesses the drought condition and makes a recommendation to the Secretary of Housing and Urban Development, who recommends action to and by the President. If the conditions warrant and the President declares a major disaster or emergency, the counties which are designated become eligible for Federal disaster assistance and other Federal relief efforts.

A vast array of Federal programs is available for specific and specialized disaster and/or emergency conditions. These programs are listed in the report entitled Digest of Federal Disaster Assistance Programs which can be obtained from the FEMA regional offices or the Minnesota and North Dakota emergency services agencies.[68]

The U.S. Geological Survey monitors streamflows on both the Red River of the North and Red Lake River. The Grand Forks area office provides the Corps with data monitored by the USGS gaging station at Grand Forks. These data may be supplied to local officials on request through the Corps or directly from the Geological Survey.

The American Red Cross, Salvation Army, and other private relief agencies can assist local governments and individuals who are affected by droughts. These agencies can provide food, shelter, clothing, and medical care, and assistance in law enforcement, fire fighting, rescue, manpower, and communications.

ATTACHMENT A
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ATTACHMENT B

LIST OF ABBREVIATIONS

mgd - million gallons per day = 1.547 cfs

cfs - cubic feet per second ≈ 0.646 mgd

mg/l - milligrams per liter

ac-ft - acre feet

gpm - gallons per minute

MG - million gallons

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ATTACHMENTS

A HEC-3 COMPUTER PROGRAM, RESERVOIR SYSTEM ANALYSIS FOR CONSERVATION

B INPUT AND OUTPUT DATA FOR PARTIAL DURATION ANALYSIS

C APPLICATION OF LFFØ1, C LOW-FLOW FREQUENCY ANALYSIS

D APPLICATION OF PROGRAM SDFØ1, C STORAGE DEPLETION-FREQUENCY ANALYSIS

E LOW-FLOW FREQUENCY DETERMINATION BY DROUGHT CULMINATION-FREQUENCY ANALYSIS

STAGE 3 LOW-FLOW FREQUENCY ANALYSIS OF THE
RED RIVER OF THE NORTH AT GRAND FORKS
AND THE RED LAKE RIVER AT EAST GRAND FORKS

SUMMARY

This report summarizes the analysis of simulated low-flow events projected to occur in the Red River of the North at Grand Forks, North Dakota, and the Red Lake River at East Grand Forks, Minnesota. Grand Forks and East Grand Forks use these two rivers as their sources of water. The objective of the analysis is to define the availability of surface water and the need for supplemental in- and/or off-channel storage.

Substantial regulation of the two rivers began in the early 1950's with construction of two major reservoirs and the improvement of the Red Lakes Reservoir control structure. Therefore, historical stream gaging records are not adequate to define future low-flow conditions and their frequency of occurrence.

The input data for the analysis are monthly average river flows generated by the HEC-3 computer program "Reservoir Analysis for Conservation." The St. Paul District conducted these simulations.

The simulated monthly river flows were then analyzed by the HEC program entitled "Partial Duration-Independent Low Flow Events." The partial duration analysis resulted in discharge-frequency-duration curves for 7 days, 14 days, 1 month, 2 months, 3 months, 4 months, 6 months, 9 months, 12 months, 2 years, 4 years, and 8 years. The results of this analysis were checked and confirmed by an independent approach.

The discharge-frequency-duration curves were used to develop mass curves of the river flow available for water supply. Mass curves were developed for low-flow events occurring on the average

of once in 20 years, 50 years, and 100 years. Projected year 2030 Grand Forks and East Grand Forks water demands were superimposed on the mass curves. The maximum divergence between the supply and demand curves represents the volume of supplemental storage required. The required storage volumes are:

Drought Return Frequency	Supplemental Storage Volume Required
20 years	240 acre-feet
50 years	500 acre-feet
100 years	630 acre-feet

In-channel storage is available in the urban area and is pooled behind the Red River of the North low head-dam and the Red Lake River low-head dam. The in-channel storage is conservatively estimated to be 3,200 acre-feet. Because there is excess storage capacity, construction of off-channel water supply storage reservoirs cannot be justified by this analysis.

Because the low-head dams provide in-channel storage and pool water for the water intakes of Grand Forks, East Grand Forks, and self-supplied industries, it is recommended that the dams be properly maintained and replaced when necessary. Also, because of the smaller in-channel storage on the Red Lake River, East Grand Forks could improve the reliability of its water supply source by constructing a backup water intake in the Red River of the North.

NEEDS AND OBJECTIVES

The objective for analyzing low-flow events is to define the availability of surface water and the need for supplemental in- and/or off-channel storage to supply the Grand Forks-East Grand Forks urban area water demands through year 2030.

A secondary objective is to determine when supplemental storage or an offsetting reduction of water demands becomes necessary. For this objective, the year when projected water demands first reach a level necessitating supplemental water supply storage to cope with a 50-year return drought is estimated. The design drought for the Grand Forks-East Grand Forks water supply study has been established as the 50-year recurrence event. However, there is peripheral interest in the 100-year event to determine if the latter's relative severity and preventive costs greatly exceed those of the 50-year event.

Currently, no existing data or previous studies adequately define the quantity of surface water available to supply the Grand Forks-East Grand Forks urban area water demands. Previous studies used data and technologies that were available at the time of those studies. More advanced technologies have been developed, including those used in this report. Also, more reservoirs have been constructed and now regulate flows on the Red River of the North and the Red Lake River. These reservoirs were constructed in the early 1950's and have significantly changed the river flow characteristics. Therefore, historical USGS (U.S. Geological Survey) stream gaging records are not

adequate to define future low-flow conditions. The three multi-purpose reservoirs used for low-flow augmentation are:

1. Red Lake Reservoir on the Red Lake River, Minnesota. The initial control structure was built in 1931; that structure was replaced by the existing control structure completed in 1952.
2. Orwell Reservoir on the Ottertail River, Minnesota. Completed in 1953.
3. Lake Ashtabula (Baldhill Dam) on the Sheyenne River, North Dakota. Completed in 1950.

Figure 1 locates these reservoirs, the major rivers, and the Grand Forks and East Grand Forks study area, all of which are in the Red River of the North basin. The Devils Lake drainage area is within the Red River of the North basin but is a closed drainage area. Lake Traverse at the headwaters of the Bois de Sioux River is used only for flood control.

Low-head dams located in the Grand Forks-East Grand Forks urban area create in-channel storage in the Red River of the North and the Red Lake River. The Red River of the North low-head dam is located about 1 mile below the confluence with the Red Lake River. The Red Lake River low-head dam is located in East Grand Forks just upstream of the confluence with the Red River of the North. Grand Forks, East Grand Forks, and the self-supplied industries obtain their water supplies from the in-channel storage pools. Grand Forks has two intakes on the Red River of the North and one intake on the Red Lake River. East Grand Forks has one intake on the Red Lake River.

The results of this low-flow analysis will be incorporated into the Stage 3 Water Supply Appendix which is part of the overall Grand Forks-East Grand Forks Urban Water Resources Study being conducted by the St. Paul District of the Corps of Engineers. The purpose of the water supply study is to develop plans for providing adequate quantity and quality of water supply to the urban area.

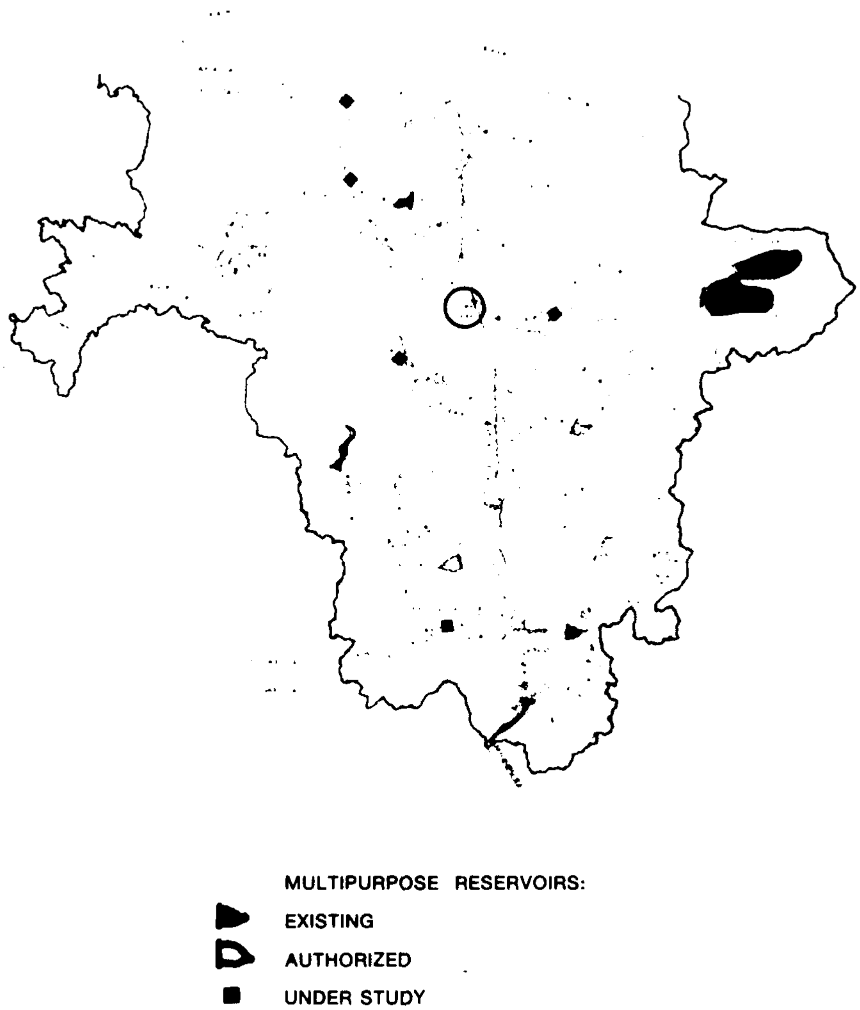

Figure 1 - Red River of the North Basin

PROCEDURES

GENERAL

The types of analyses and procedures available to analyze low-flow events are discussed in this section. The analysis of low-flow events results in a determination of the quantity of water available to satisfy Grand Forks and East Grand Forks water demands. Following that determination, the need for supplemental storage and the volume of storage required can be determined.

AVAILABLE PROCEDURES

The procedures for estimating water supply storage volumes required to supplement the flows available in a river are as follows:

1. Flow-Mass Curve analysis of historical record (Rippl Method).[1]

   The flow-mass curve is derived by plotting accumulated daily, weekly or monthly volumes of inflow versus time. The desired gross average draft rate (water supply demand plus evaporation and seepage losses) is represented by a straight line of constant slope superimposed on the streamflow mass curve diagram. Such lines are constructed tangential to high points on the mass diagram and extended forward until they rejoin the mass curve. Divergence between draft line and mass curve represents depletion of reservoir storage. The value of maximum divergence obtained over the entire period of record may be used as a basis for estimating

storage requirements for a proposed supply. The procedure is regarded as approximate since it designs for the worst case on record but provides little indication of probability of failure of the design storage so derived.

2. Frequency-Mass Curve Analysis (Nonsequential Mass Curve Method).

This procedure requires two steps. Low-flow frequency curves based upon minimum average flows for various durations (typically 1 month, 2 months, 3 months, 6 months, etc.) are first computed by sequential analysis of the period of record. Flows of any given duration are arranged in ascending order of magnitude and plotting positions are assigned. The discharge-frequency relationships are plotted on suitable paper to produce a low-flow frequency curve for a given duration. The method thus includes graphical smoothing of the data and enables identification of "outliers" or events regarded as exceptional for the period of historical record.

Low flows of all durations for a specified design frequency are derived from the low-flow frequency curves and are assumed to constitute enveloping conditions of a "design" low-flow hydrograph of the particular frequency. A streamflow mass curve is constructed from these curves, and the point of maximum divergence between the gross average draft (demand) rate and mass curve yields reservoir storage requirement for this frequency. It is common practice to increase storage requirements obtained by this method by 10 percent.[2]

3. Storage Deficiency-Frequency-Mass Curve Analysis[3,4]

The storage depletion-frequency analysis results in a mass curve similar to the flow-mass curve

approach. Peak storage demands are identified by superimposing the draft (demand) rate curve on the mass diagram. Peak storage demands are obtained for each storage depletion. The frequency of storage depletion and the magnitude of the depletion are rank ordered, analyzed, and result in the storage deficiency-frequency curve. This procedure has the advantages of recognizing seasonal differences in water demand, varying the storage losses for different conditions, and using all data rather than low-flow samples.

SELECTED PROCEDURE

The selected procedure for the initial and primary analyses of low-flow events is the Frequency-Mass Curve Analysis. This procedure is commonly used in the field, is widely accepted, and is relatively inexpensive to use. The results obtained by the selected procedure were checked and verified by several additional computational analyses and the Storage Deficiency-Frequency-Mass Curve Analysis.

The input data for the low-flow frequency analysis were provided by the St. Paul District of the Corps of Engineers. These data are the simulated monthly average flows for the homogeneous period of record from 1930 to 1976. The Hydrologic Engineering Center HEC-3 computer program "Reservoir System Analysis for Conservation" was used to develop the simulated data.[5] This program and its simulated flows are also being used by the Corps for its overall Red River of the North Basin Study.[6] The program procedures and the adjustment of that program's results are discussed in Attachment A. A list of the input and output data is presented in Attachment B.

In the Frequency-Mass Curve Analysis, the adjusted input data are analyzed by a low-flow frequency partial duration analysis. The partial duration analysis uses the Hydrologic

Engineering Center program entitled "Partial Duration-Independent Low Flow Events."[7] Discharge-frequency-duration curves are developed for durations of 7 days, 14 days, 1 month, 2 months, 3 months, 4 months, 6 months, 9 months, 12 months, 2 years, 4 years, and 8 years. This HEC program computes discharges and frequencies for durations of 2 months and longer. The program accumulates flow volumes for a given duration throughout the entire period of record. The flow volume is converted to an average flow rate. These flow rates are then successively scanned to locate low-flow events in ascending order of magnitude (smallest first). These events are selected without regard to the calendar year and in such a manner as to ensure their chronological independence. To avoid overlapping of data, say for a 12-month duration, the prior and subsequent 11 cumulative flows are excluded from further consideration. The initial 11 volumes at the beginning of the record (for a 12-month duration) are also excluded because they do not represent full duration volumes. The latter exclusion is used in determining the effective number of years of record which is subsequently used in computing the exceedence frequency (plotting position).

The plotting positions for the various durations are calculated by Beard's Method.[8] The number of events to be considered is limited to the smaller of the following two conditions:

1. A recurrence interval no smaller than 2 years.
2. The total number of monthly periods divided by the months of duration.

Neither condition will be reached when the ratio of total months of record to months of duration is small because of the nonoverlapping stipulation. Beard's Method uses the following equation:

$$1 - P_1 = (0.5)^{1/N}$$

where:

P_1 = plotting position for the smallest event in exceedance frequency expressed in percent.

N = number of years of record.

The plotting positions for the largest event is the complement of this value, and all other plotting positions are interpolated linearly between these two. The recurrence interval in years is computed by $T_i = 1/P_i$ divided by the number of durations per year. For example, there are four durations of 3 months in length per year.

To supplement the data provided by the HEC's partial duration program, durations of 1 month are computed by analyzing the simulated monthly average flows generated by the HEC-3 program. The monthly flows are arrayed in ascending order, the Beard's plotting positions are calculated, and the return frequency in years is computed. This procedure is the same as used in the HEC "Partial Duration-Independent Low Flow Events" analyses. Low flows for 7- and 14-day periods are derived by determining the ratio of these flows to the 1-month flows. The ratio relationships are developed from the USGS gaging station records which include both the unregulated and regulated flows. The historical data relationships were applied to the simulated 1-month duration flows to derive the 7- and 14-day duration curves.

The discharge-frequency curves for durations longer than 12 months are adjusted by the method discussed in the report entitled Kansas Streamflow Characteristics, Part 4, Storage Requirements to Sustain Gross Reservoir Outflow.[9] The adjustment is needed because there are not enough independent events in the 47-year period of record to define the long duration discharge-frequency curve. The adjustment prevents the discharge-frequency curve for multiyear durations from having a higher discharge at a 50-percent exceedence frequency than the mean discharge. For example, over a long period, the flow in a stream cannot exceed its average discharge.

The Kansas adjustment procedure shapes the discharge-frequency curves for durations greater than 12 months. The procedure is

based on the 12-month curve and the mean discharge. The curves are sketched to develop a family of curves rather than adhering to specific data. This causes some reservations. However, the discharge-frequency-durations which are of concern in the Grand Forks-East Grand Forks area are not affected by the adjustment.

Attachment E summarizes an alternative method to the Kansas adjustment procedure. This method is a drought culmination-frequency analysis and determines reservoir requirements for long duration droughts. The concept is a statistical analysis derived by considering the probability of a given duration drought ending in any water year. Thus, as the drought ends, reservoir drawdown will be at a maximum, which is the critical design condition experienced before the drought "breaks." This method is being considered by the Hydrologic Engineering Center. However, because of the time frame for this study, the Kansas adjustment procedure will be used.

Although the HEC "Partial Duration-Independent Low Flow Events" program is the selected procedure for the low-flow analysis, an independent check was made. A computer program (LFF01,C) was developed and is described in Attachment C. LFF01,C includes several modifications which are not included in the HEC program. These include the direct calculation of the 1-month duration-discharge-frequency curve and computation of recurrence intervals down to 1 year or the total number of independent low-flow durations if the number is less than the number of years of data. The HEC program does not compute recurrence intervals below 2 years. This is adequate for most studies for which the main area of concern lies in the 20-year to 50-year range of recurrence intervals. However, in the Grand Forks-East Grand Forks area, the 1-year to 2-year recurrence intervals are needed to more fully understand the streamflow characteristics and assist the drawing of low-flow frequency curves.

LFF01,C and the HEC program were found to yield essentially identical results for durations of 2 months and longer. This check adds confidence to the HEC program results. Computation of the 1-month duration flows indicates that there are two distinct statistical "populations" of flows. One at the high flows and the other at the low flows. The reservoir low-flow augmentation creates a reverse curvature in the discharge-frequency-duration curves. At high flows, a more common curvature exists, but at low flows, the curve is raised and flattened. Therefore, the curves are "S" shape rather than single curvature.

After the discharges and frequencies are computed for each duration, a family of low-flow frequency curves can be plotted. The selected plotting method was developed by Gumbel.[10] Plotting based on Cartesian coordinates and log probability grids resulted in rather abrupt curves at the upper and lower ends. Also, the extreme values, in which there is the greatest interest, were compressed into a very small area. Therefore, the Gumbel plotting method is used to produce a straighter line. This method is particularly applicable because the lower limit of flow approaches zero. The method is a distribution of the exponential type which converges to an exponential function as "x" increases. Linearization of this distribution is made on logextremal probability paper which is obtained by the following equation:[11]

$$K = -\frac{\sqrt{6}}{\pi}\left[0.57721 + \ln \ln\left(\frac{T}{T-1}\right)\right]$$

where:

K = Gumbel plotting position or frequency factor.

T = Yearly recurrence interval.

The extreme low-flow events that occurred during the 1930's are within the 47-year period of record analyzed by the HEC-3 program. Based on the partial duration analysis and the Beard's plotting method, the extreme events have a recurrence frequency

of 67.0 to 68.2 years for durations of 12 months or less. However, discussions with Corps personnel indicate that a longer recurrence frequency should be assigned to the extreme events. This conclusion is based on analyses performed by the Corps. The Corps used its HEC-4 computer program "Monthly Streamflow Simulation" to stochastically extend the 47 years of streamflow data.[12] Four hundred years of synthetic data were generated. However, the 1930's drought could not be reproduced. Reasons given were there was no long-term buildup to the 1930's drought and the extreme duration of the 1930's drought prevented the regression analysis from simulating the extreme low-flow events. Also, the LFF01,C computations indicate that there are two statistical "populations" of river flow. The first occupies almost the entire range of normal flows and has abundant data to establish a frequency distribution relationship. The second "population" extends through the range of low flows when low-flow augmentation effects from upstream reservoirs become significant. This lower range of flows requires a different model for generating synthetic flows because few data points are available. The synthetic extension of historical data would be applicable in some cases, but should not be used for the Grand Forks-East Grand Forks area until a more sophisticated model can be derived.

The extreme low-flow events must still be assigned a recurrence frequency. The USGS studied the frequency of low-flow events on the Red River of the North in a 1962 report.[13] That report concluded that although evidence may not be adequate to warrant assignment of a definite recurrence interval to the minimum flows of the 1930's, it supports a conclusion that the minimums were probably the lowest that occurred during a period of at least 150 years.

Discussion with Corps personnel concluded that the extreme low-flow events defined by the partial duration analysis

would be assigned a 200-year recurrence interval.[14] The discharge-frequency-duration curves were extended in response to this adjustment.

Mass curves can be developed from the family of discharge-frequency-duration curves. These curves are plots of the quantity of flow in cfs-days versus duration in days. Since the partial duration analysis is a statistical evaluation, the mass curve is a presentation of the cumulative discharge for a statistical return frequency. Mass curves for 20-year, 50-year, and 100-year recurrence frequencies are developed. These curves help determine the minimum drought frequency necessitating supplemental water supply storage to meet yearly demands.

The volume of required in- and/or off-channel storage for water supply is determined from the mass curve. The Grand Forks and East Grand Forks water demands are superimposed on the mass curve. The maximum difference between the water demand curve and the streamflow mass curve represents the quantity of supplemental storage required.

Evaluation of the Frequency-Mass Curve Analysis and the HEC-3 data indicates that the following deficiencies should be recognized:

1. Daily rather than monthly flows provide more accurate results; however, use of daily flows would require a considerable increase in computational effort. Monthly flows probably give a slightly low estimate of storage but are adequate for planning purposes.
2. Channel losses (evaporation and seepage) are difficult to predict during extreme low-flow events because of a lack of data. The HEC-3 program is not sensitive enough to predict effects during these events. The allowance of the minimum 8 cfs passing Grand Forks and 3 cfs passing East Grand Forks provides some safety

factor. Also, it is assumed that the HEC-3 data satisfactorily simulates stream flows, but does not adequately account for evaporation losses in in-channel storage pools.

3. The input data for the HEC-3 program is net withdrawals (withdrawals minus discharges). When the discharges exceed the withdrawals, the river flow would experience a net increase or a negative net withdrawal. However, the HEC-3 program cannot handle negative withdrawals, so the input data for negative withdrawal values is zero. Based on year 2030 projected demands and discharges, zero values are assigned to Red River of the North flows at Grand Forks for 7 of 12 months and to Red Lake River flows at East Grand Forks for 2 of 12 months. Therefore, an additional safety factor is built into the HEC-3 projected river flows.
4. Water demands upstream of Grand Forks and East Grand Forks include irrigation uses that are included in the HEC-3 simulations. Under Minnesota law, permits for irrigation uses can be cancelled during droughts to ensure that municipal-domestic demands can be satisfied. North Dakota water use permits are based on the first permit-first right basis. However, most irrigators probably would discontinue irrigation during severe droughts. Therefore, inclusion of irrigation uses builds another safety factor into the analysis.
5. The 47-year period of records does not provide enough data points to accurately predict long droughts.
6. The streamflow mass curve is developed from a statistical analysis and disregards timing of low flows. The 7-day and other low flows can occur in any month. Highest water demands can also occur in any month,

and the low flows and highest demands may not coincide. Therefore, the frequency-mass curve analysis cannot examine the effects of seasonal streamflow and demand fluctuations.

7. The presence of a bias in the frequency-mass curve analysis leading to an underestimation of the storage requirement by about 10 percent has been reported by several investigators.[2,15] This is partly due to fluctuation of discharge within the monthly input period, partly to possible inaccuracy in plotting positions selected for the frequency curves, and possibly to other causes.

An independent check on the results of the Frequency-Mass Curve Analysis may eliminate at least part of the inherent bias and other problems listed above. The Storage Depletion-Frequency Analysis is a satisfactory approach to the independent check. A computer program (SDF01,C) has been written and is discussed in Attachment D. The check compared favorably to the initial results. Differences did occur at the low-flow extremes which are of greatest concern. Because the amount of bias inherent in both approaches cannot be accurately predicted, a range of storage volumes could be used for design purposes.

RESULTS

The first analysis of low-flow events involved:

1. Year 2030 water demands.
2. Existing reservoir operation.

The HEC-3 Run #16 used these conditions to simulate monthly average streamflows. A slight modification was made to shorten the time requirèd to balance the system. Previous runs had shown that releases from Lake Ashtabula (Baldhill Dam) and Orwell Reservoir did not have a significant impact on the water supply at Grand Forks and East Grand Forks. Therefore, in Run #16, Lake Ashtabula and Orwell Reservoir were operated only for communities and channel losses upstream of Grand Forks and East Grand Forks. Red Lakes Reservoir was operated in its normal pattern to satisfy Grand Forks and East Grand Forks water demands.

Run #16 "River Flows" were modified to reflect the average flows available as a water supply source. The year 2030 projected annual average water demands for Grand Forks (27 cfs) and East Grand Forks (3 cfs) were added back to the "River Flows." The Run #16 projected water demands vary slightly from those projected by the ongoing stage 3 water supply investigations:

Year 2030 Water Demand Projections

	Run #16	Stage 3
Grand Forks	27.21 cfs	21.15 cfs
East Grand Forks	3.37 cfs	4.42 cfs
TOTAL	30.58 cfs	25.57 cfs

The stage 3 projections reflect more detailed analyses and will be used for the water supply storage analysis. Under most cases,

the HEC-3 simulations indicate that the higher demands can be satisfied, so an additional safety factor is built into the analysis.

Run #16 predicted only one period of flow insufficient to satisfy year 2030 projected water demands. The Red River of the North could not satisfy Grand Forks and East Grand Forks water demands and the minimum 8-cfs flow passing Grand Forks during August 1936 simulated flows. The Red Lake River could not satisfy East Grand Forks water demands during simulated August and September 1936 conditions. These conditions result because the water level in the Red Lakes Reservoir fell below its designated minimum conservation pool. At this point, the discharge is reduced from an average rate of 50-cfs to 15-cfs maximum discharge. These discharges are specified by the provisions of a treaty with the Red Lake Band of the Chippewa Indians. These shortages are reflected in the partial duration analysis.

Figure 2 shows the results of the partial duration analysis for the Red River of the North at Grand Forks. The family of low-flow discharge-frequency-duration curves for 7 days through 8 years is presented. These curves represent the average flow rates available to satisfy Grand Forks and East Grand Forks projected year 2030 water demands. These curves also indicate that the basin reservoirs have a significant effect on streamflow. At recurrence intervals greater than 10 to 20 years, reservoir low-flow augmentation releases maintain higher flows than have historically been observed; thus, the "S" curve shapes. Discontinuities in the spacing between curves is probably due to the way the HEC-3 program releases flow from the reservoirs. During dry periods, the minimum allowable flows are released, but during wet periods, the maximum flow quantities are released. For example, a dry period of about 9 months followed by spring runoff would produce a significant difference between the 9-month and

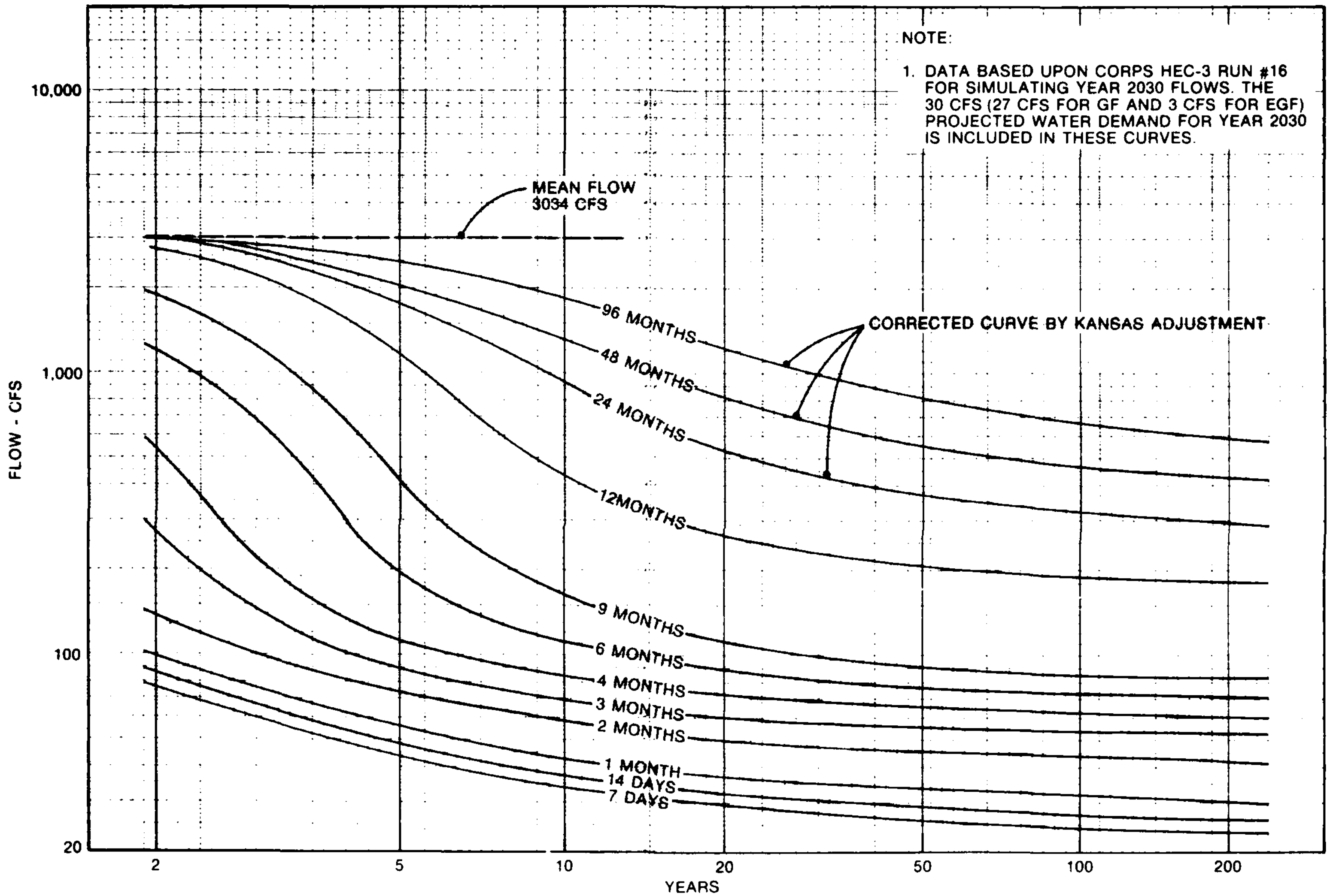

Figure 2 - Low-Flow Frequency Curves, Red River of the North at Grand Forks

longer duration curves. The curves also reflect the assignment of a 200-year return frequency to the extreme low-flow events experienced during the 1930's drought.

Figure 3 presents the family of low-flow discharge-frequency-duration curves for the Red Lake River at East Grand Forks. These curves reflect the average flow rates available to satisfy East Grand Forks projected year 2030 water demands. There is not enough data to guide the extension of the curves beyond a 20-year recurrence frequency. The Red Lakes Reservoir has a significant impact on the river flows due to its low-flow augmentation. Therefore, extrapolation of the curves from the 20-year to 200-year recurrence frequencies cannot rely on the shape of the curves between recurrence frequencies from 2 years to 20 years. Also, the Red Lakes Reservoir operates to satisfy water demands and minimum downstream flows (3 cfs passing East Grand Forks and 8 cfs passing Grand Forks) which tends to weight low flows toward the 3- and 8-cfs values.

Figure 4 presents the mass curves for the Red River of the North at Grand Forks. The mass curves for 20-year, 50-year, and 100-year recurrences are shown. The mass curves were obtained from the family of discharge-frequency-duration curves by multiplying the average flow rate times the duration in days to obtain cfs-days. These quantities were adjusted to allow the minimum 8 cfs to pass below Grand Forks. The cumulative flow is shown only through about 6 months because the quantity of streamflow exceeds the cumulative water demand.

Figure 5 is a blow-up of the 1-month period shown on figure 4. The Grand Forks and East Grand Forks year 2030 water demand curve is superimposed on the streamflow mass curves. The maximum divergences between the demand and streamflow curves are the net quantities of supplemental water supply storage required. An allowance of 10 percent is added in accordance with the Frequency-Mass Curve Analysis procedure.

As indicated previously, the HEC-3 program simulates streamflows but does not account for evaporation losses associated with in- and/or off-channel storage reservoirs. Therefore, an evaporation loss must be added to the required storage volumes. Evaporation losses are based on an evaporation of 28 inches per year and are estimated to be about 5.6 inches in 1 month and about 34.5 inches in 450 days.[16] Storage lost to evaporation depends on the reservoir surface area. In-channel storage has a relatively large surface area because the river slopes are relatively flat. Off-channel reservoirs store only the quantity of water needed, so the surface area is minimized.

Figure 5 indicates that water supply shortages would be experienced for approximately 30 days during a 50-year drought event. Flows from both the Red River of the North and the Red Lake River are used to satisfy Grand Forks and East Grand Forks water demands. The storage requirements for various drought return frequencies are as follows:

Drought Return Frequency (years)	In-channel Storage: Base Storage Required (ac-ft)	Evaporation: Duration (days)	Evaporation: Loss (ac-ft)	Total Storage Required (ac-ft)
20	60	17	180	240
50	130	29	370	500
100	180	35	450	630

In-channel storage surface areas pooled behind the low-head dams are about 600 acres on the Red River of the North and 200 acres on the Red Lake River.

Off-channel storage reservoirs were also considered. Evaporation adds about 1.3 acre-feet of storage base on 17-days duration, 5 acres of surface area, and 15-foot working depth in the reservoir. For 35-days duration, evaporation adds about 7.3 acre-feet of storage to the base storage required. The added storage is based on 15 acres of surface area and 15-foot working depth.

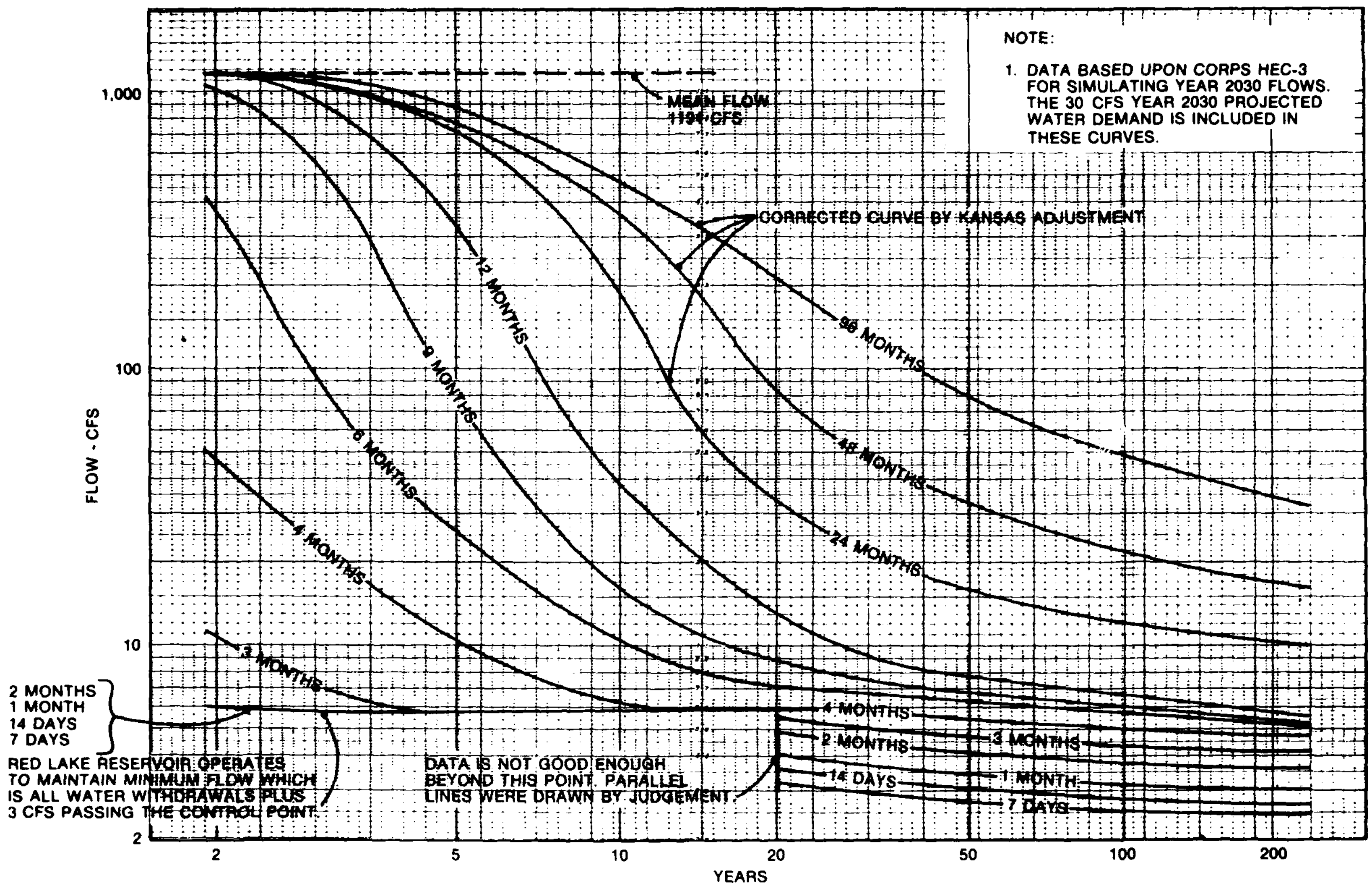

Figure 3 - Low-Flow Frequency Curves, Red Lake River at East Grand Forks

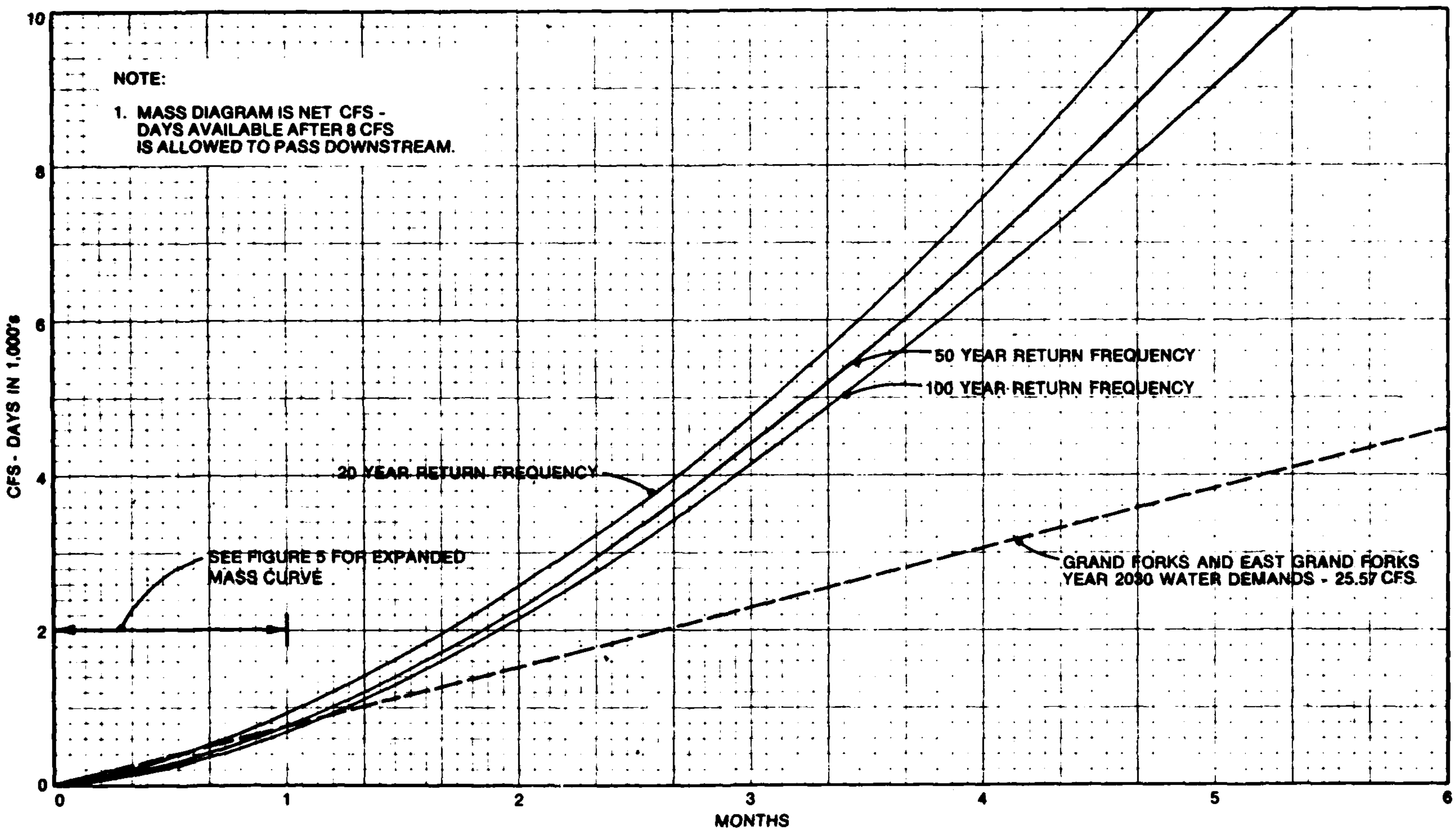

Figure 4 - Mass Curve for the Red River of the North at Grand Forks

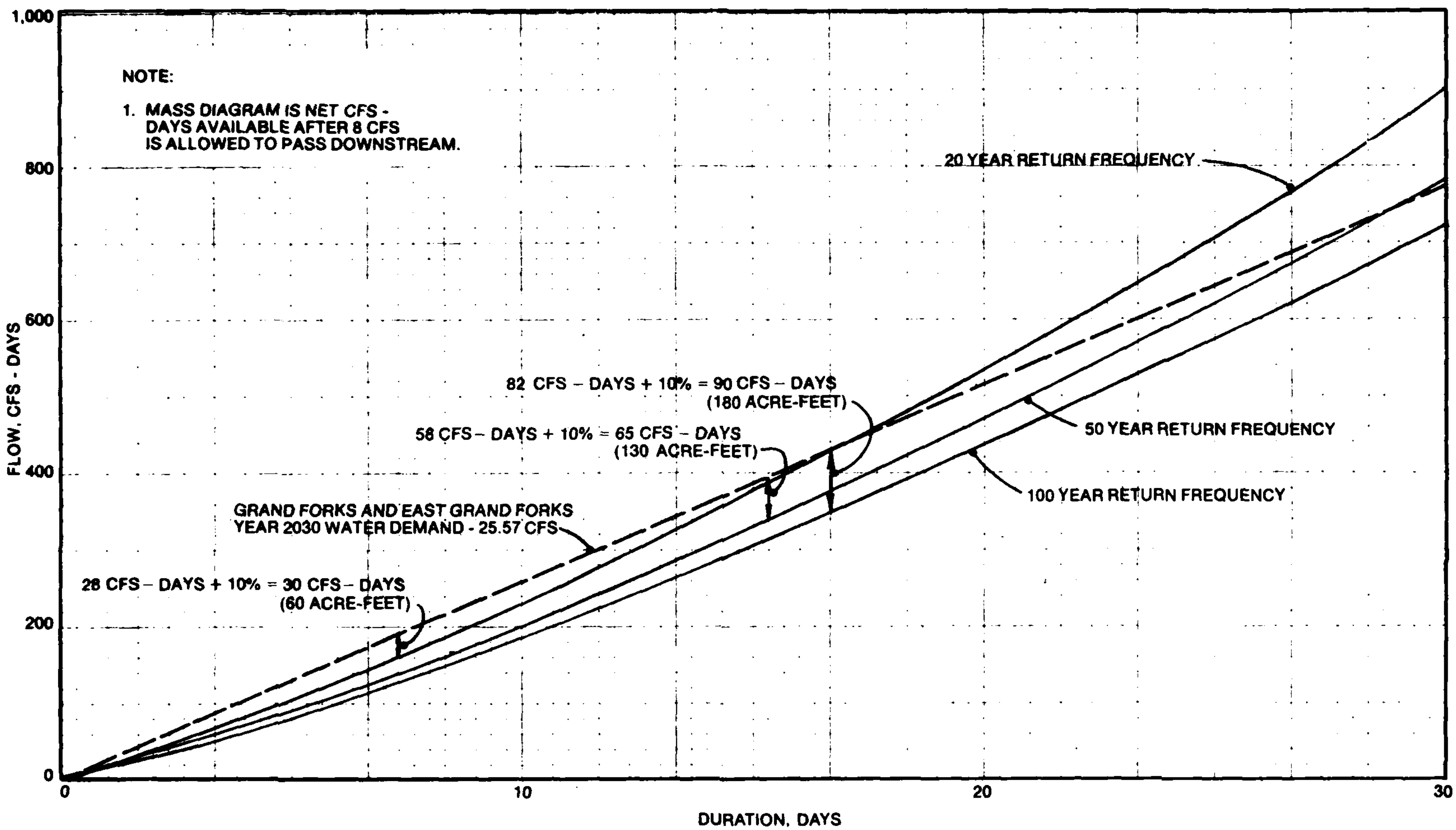

Figure 5 - One Month Duration Mass Curve for the Red River of the North at Grand Forks

Figure 6 presents the mass curves for the Red Lake River at East Grand Forks. The mass curves for 20-year, 50-year, and 100-year return frequencies are shown and include the adjustment for the minimum of 3 cfs that must be allowed to pass below East Grand Forks. Water supply shortages would be experienced based on year 2030 projected water demands. Shortages occur for two reasons:

1. There are periods when the projected water level in the Red Lakes Reservoir falls below the minimum conservation pool.
2. The water shortage is increased because the year 2030 projected water demand is 4.42 cfs rather than 3 cfs as used in the HEC-3 model.

The Red Lakes Reservoir can at most times operate to satisfy the 4.42-cfs demand, but for the 2 months when the reservoir level is below the minimum conservation pool, storage would still be needed. Storage would also be required at a 3-cfs demand, but the duration and magnitude of the shortage would be decreased.

Based on figure 6, the water shortages and the volume of storage required to satisfy East Grand Forks demands during various drought return frequencies are as follows:

Drought Return Frequency (years)	In-channel Storage: Base Storage Required (ac-ft)	Evaporation: Duration (days)	Evaporation: Loss (ac-ft)	Total Storage Required (ac-ft)
20	380	186	420	800
50	520	270	450	970
100	720	450	610	1,330

Evaporation losses are based on the Red Lake River storage pool only. The in-channel storage surface area is about 200 acres. If off-channel storage reservoirs are used, evaporation losses add about 60 acre-feet of storage based on 180 days duration,

30 acres of surface area, and 15-foot working depth. For 450 days duration, evaporation adds about 150 acre-feet of storage based on 50 acres of surface area and 15-foot working depth.

The available in-channel storage pooled behind the existing low-head dams on the Red River of the North and the Red Lake River is estimated as follows:

	In-channel Storage Volume (ac-ft)
Red River of the North	2,200
Red Lake River	1,000
TOTAL	3,200

All readily available sources have been used for this estimate. Cross sections and thalweg elevations surveyed in 1944, 1972, and 1979 indicate that the river channel elevations have not varied greatly with time.[17,18,19,20] Evidently, the river pools have stabilized, and the accumulated sediment is scoured by high flows. The pools behind the dams extend for a considerable distance because of the extremely flat channel slopes in the area. The river bottom slopes through the Grand Forks and East Grand Forks area are reported to be 0.4 foot per mile for the Red River of the North and 1.6 feet per mile for the Red Lake River.[17,19,21] At 0.4 foot per mile and an average water depth of 15 feet at the low-head dam, the Red River of the North pool extends 37.5 miles upstream. The Red Lake River pool extends about 10.6 miles upstream based on the 1.6-foot-per-mile slope and a water depth of 17 feet. This water depth is greater than that in the Red River of the North because the low-head dam crest elevation is 796.8 feet versus the Red River of the North low-head dam elevation of 794.3 feet. An allowance of 5 feet for sediment buildup between high-flow scours has been included in the estimated storage volumes.

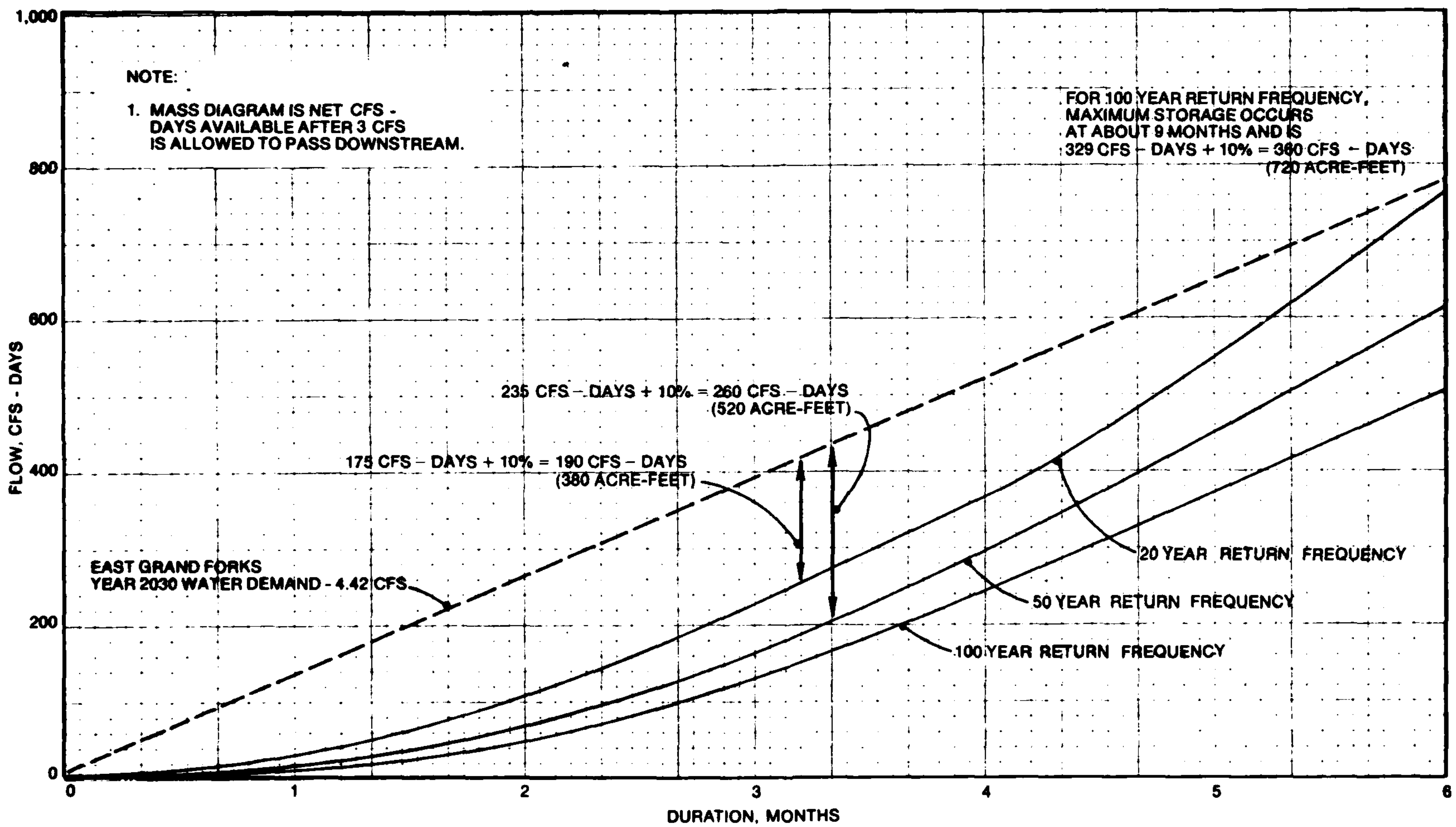

Figure 6 - Mass Curve for the Red Lake River at East Grand Forks

The above analysis indicates that the combined Red River of the North and Red Lake River flows plus their in-channel storage can satisfy Grand Forks and East Grand Forks urban area projected water demands through year 2030. In-channel storage exceeds the required supplemental storage for the 50-year design drought and for droughts with at least a 100-year return frequency. Therefore, no additional off-channel storage is recommended. Continued maintenance and/or replacement of the low-head dams is important for maintaining in-channel storage capacity.

For the Red Lake River serving just East Grand Forks, river flow and in-channel storage can satisfy East Grand Forks projected water demands through year 2030 for up to the 50-year return frequency drought. To satisfy the 100-year drought, 330 acre-feet of off-channel storage would be required. Total land area for water storage, dikes, and access is estimated to be about 60 acres. East Grand Forks could satisfy these supplemental storage needs by constructing a backup water intake in the Red River of the North. More detailed analyses would be required to determine the most feasible and cost-effective solution. However, since the design drought is the 50-year recurrence event, no off-channel supplemental storage is recommended.

The Corps has operated the HEC-3 model for other water demand and reservoir discharge conditions. The range of water demands included projected usages for existing, 1980, 1990, 2000, and 2030. In general, changing water demands have minor impact on the streamflow at Grand Forks and East Grand Forks. One period of shortage still occurs because the water level in the Red Lakes Reservoir falls below its minimum conservation pool and water releases are reduced from 50 cfs to 15 cfs. The magnitude of the shortage increases with increased water demands.

The water demand curves shown on figures 4, 5, and 6 show this effect. On figure 6, if the water demand was 3 cfs rather

than 4.42 cfs, the base supplemental storage requirements for the 50-year drought would be about 240 acre-feet for 150 days duration rather than 520 acre-feet for 270 days duration. However, the shortage still occurs and supplemental storage is required.

The evaporation losses over the 450-square mile surface area of the Red Lakes Reservoir has a significant impact on the streamflows. Run #17 operated the Red Lakes Reservoir to discharge 50 cfs rather than 15 cfs when the operating level fell below the minimum conservation pool. All water demands could be satisfied and no shortages resulted. Releasing 50 cfs did not significantly affect the water level in the Red Lakes Reservoir. This indicates that evaporation has a more significant impact on this reservoir than water demands.

CONCLUSIONS AND RECOMMENDATIONS

The low-flow frequency analysis indicates that Red River of the North and Red Lake River flows cannot continuously satisfy the Grand Forks-East Grand Forks urban area water demands. During extreme low-flow events, the Red Lakes Reservoir water level falls below its minimum conservation pool and the reservoir discharge is reduced from 50 cfs to 15 cfs. Supplemental storage is required to supply water demands during extreme low-flow events.

The low-flow frequency analysis for the control point on the Red River of the North at Grand Forks includes the Red Lake River and is below the water intakes of Grand Forks, East Grand Forks, and self-supplied industries. All urban area water demands and water supplies are included at this control point. The duration of the shortages and volumes of supplemental water supply storage needed to satisfy the urban year 2030 water demands for various return frequencies are:

Drought Return Frequency (years)	Shortage Duration (days)	Volume of Supplemental Storage Required (acre-feet)
20	17	240
50	29	500
100	35	630

A conservative estimate of the existing in-channel storage capacity indicates that 3,200 acre-feet of storage is available to supplement natural streamflows. Therefore, construction of an

off-channel water supply reservoir cannot be justified by this analysis.

A similar analysis was conducted for the control point on the Red Lake River at East Grand Forks. Only East Grand Forks water demands were to be satisfied by the Red Lake River. Supplemental storage would be required as follows:

Drought Return Frequency (years)	Shortage Duration (days)	Volume of Supplemental Storage Required (acre-feet)
20	186	800
50	270	970
100	450	1,330

The existing in-channel storage behind the low-head dam on the Red Lake River is estimated to be 1,000 acre-feet. This storage capacity exceeds the volume of supplemental storage required to satisfy East Grand Forks projected water demands for up to the 50-year design frequency drought. Therefore, construction of an off-channel storage reservoir is not required.

The above summaries indicate that the low-flow augmentation reservoirs built and improved in the early 1950's can maintain streamflows except during extreme drought periods. During extreme drought periods, in-channel storage supplements natural streamflows to supply the urban area water demands. In-channel storage capacity is adequate when the combined Red River of the North at Grand Forks control point is considered and up to the 50-year drought when just the Red Lake River serving East Grand Forks is considered. Since the design criteria calls for satisfying water demands during the 50-year drought, no additional off-channel storage is required. Also, East Grand Forks could improve the reliability of its water supply source by constructing a backup water intake in the Red River of the North.

For projected year 2030 water demands, the low-flow frequency analysis indicates that supplemental storage is required for all droughts that have a return frequency greater than about 10 years. Thus, without in-channel storage, a water supply shortage would be experienced every 10 years.

Partial duration analyses for projected 1980, 1990, and 2000 water demands and modified reservoir operations were not conducted because available in-channel storage can satisfy the worst case conditions. However, by observation, supplemental storage would be required even for 1980 demands when the Red Lakes Reservoir releases are reduced from 50 to 15 cfs, essentially none of the released flow reaches the urban area. Also, by observation, as water demands become smaller or more water is released from upstream reservoirs, the duration and magnitude of the shortage and, therefore, the required supplemental storage volume, become smaller.

Since the in-channel storage capacity exceeds the required supplemental storage, no off-channel storage is required. However, because the low-head dams maintain the in-channel storage and pool water for the water intakes of Grand Forks, East Grand Forks, and self-supplied industries, it is recommended that the low-head dams be properly maintained and replaced when necessary. Also, because the Red Lake River in-channel storage is relatively small, East Grand Forks could improve the reliability of its water supply source by constructing a backup intake in the Red River of the North.

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ATTACHMENT A

HEC-3 COMPUTER PROGRAM

RESERVOIR SYSTEM ANALYSIS FOR CONSERVATION

The HEC-3 program was used to route historic monthly flows through the reservoirs and streams in the Red River of the North basin. The program accounts for reservoir storage depletions, downstream flow diversions, reservoir releases to meet specified water needs, reservoir evaporation losses, reservoir routing functions, and channel transmission losses. All water requirements are supplied from the basin reservoirs in a manner which will balance the remaining storage as far as possible. For example, at reservoir stages below specified levels, releases from storage are reduced to a bare minimum to cover downstream water needs. At high levels, additional water is released to return the reservoir to its designated balance level (conservation pool).

The HEC-3 program was calibrated by first developing a homogeneous record of natural flows based upon unregulated flows. Flow records are based upon USGS gaging station data. These data points reflect unregulated flows prior to reservoir development in the early 1950's and regulated flow thereafter. Unregulated flows were computed for the period 1930 through 1976 (47 years).

Regulated river flows since the start of operation of Corps reservoirs in the early 1950's were adjusted to natural flows by determining or calculating reservoir inflows and adjusting the regulated flows downstream with the aid of the HEC-3 program. Then estimated historic water withdrawals for municipal, industrial, and livestock use were added to the adjusted flows to produce

estimated natural flows without diversions or depletions.

The HEC-3 program was then operated for designated design conditions. These conditions include specified water withdrawals such as projected year 2030 demands and specified reservoir operation corresponding to different water levels in the reservoir. Thus, the HEC-3 program simulates monthly average river flows that would occur under a specified set of conditions. For example, the estimated effect of the 1930's drought that would be experienced in year 2030, including the effect of the addition of reservoirs and the increased water demands, can be simulated.

The HEC-3 program calculates the river flow rate that passes a control point. This "River Flow" accounts for all inflows and diversions including the Grand Forks and East Grand Forks water withdrawals and all industrial, irrigation, and livestock watering demands. However, the partial duration analysis should consider the total flow available to satisfy Grand Forks and East Grand Forks water demands and to refill water supply storage reservoirs. Therefore, projected water demands for Grand Forks and East Grand Forks were added to the "River Flow" to derive the total flow.

Another reason for adding the water demands to the "River Flow" is the occurrence of several cases where the "River Flow" was zero but only part of the required diversion was satisfied. The zero flows biased the partial duration analysis. Also, the program tries first to satisfy water demand diversions, then to satisfy the minimum flow that must pass downstream. However, under current assumptions, the minimum downstream flow must be allowed to pass before water demand diversions are satisfied. The minimum flow provides a safety factor for the water needs analysis and ensures that some minimal water flow is maintained for sanitation purposes. The minimum designated flows are 3 cfs below East Grand Forks and 8 cfs below Grand Forks.

ATTACHMENT B

INPUT AND OUTPUT DATA FOR PARTIAL DURATION ANALYSIS

This attachment lists the inputs, outputs, and assumptions for the partial duration analysis of the "worst case" situation.

Assumptions:

1. Year 2030 projected water demands.
2. Reservoirs operated under current regulatory policies.
3. Lake Ashtabula (Baldhill Dam) and Orwell Reservoir are not operated to satisfy Grand Forks and East Grand Forks water demands.

The input data were generated by the HEC-3 computer program "Reservoir Analysis for Conservation."

```
      PROGRAM CH045
C     RESERVIOR YIELD
C     PARTIAL DURATION - INDEPENDENT EVENTS
C     PROGRAMMER- W.L. SHARP         PROGRAM NO. 23-J2-J247   FOR 18M
C     SELECTION OF LOW FLOW PERIODS FROM PERIOD OF RECORD FLOWS
C     BASED ON NO OVERLAP OF DURATIONS
C     LIMITED TO 1000 YEAR FLOW RECORD AND 20 DURATIONS
      DIMENSION MONDUR(20),FLOW(1000),ACCUM(1000)
  100 FORMAT(10F8.0)
  110 FORMAT(10I8)
  111 FORMAT(20A4)
      CALL ASSIGN(5,'CR0:',4)
      CALL ASSIGN(6,'SY:CH045.SPR',12)
      REWIND 6
  112 ICYCLE=0
C     READ THREE TITLE CARDS
      READ(5,111,END=500)(FLOW(I),I=1,60)
      WRITE(6,111)(FLOW(I),I=1,60)
      READ(5,110)M1,MON1,IYR1,LMON,LYR,INUNIT
      READ(5,100)DA
      READ(5,110)(MONDUR(N),N=1,20)
      J=(LYR-IYR1)*2+2
      N=1
      K=6
      DO 120 I=1,J
  115 FORMAT(2A4,I8,6F8.0)
      READ(5,115)ID,ID,IYR,(FLOW(NN),NN=N,K)
        DO 118 IZYX=N,K
118     FLOW(IZYX)=FLOW(IZYX)+30.
      N=K+1
  120 K=K+6
      NP=K-6
      IF(MON1-M1)122,124,124
  122 I1=12+MON1-M1
      GO TO 125
  124 I1=MON1-M1
  125 IF(LMON-M1)126,127,127
  126 I2=M1-LMON-1
      GO TO 128
  127 I2=LMON-12+M1-1
  128 XNP=NP-I1-I2
      NP=NP-I2
      IYEARS=XNP/12.0
      YEARS=IYEARS
      MONTHS=XNP-(YEARS*12.0)
  130 ICYCLE=ICYCLE+1
      IF(ICYCLE-20)140,140,400
  140 MD=MONDUR(ICYCLE)
      IF(MD)400,400,150
C     COMPUTE BEARDS PLOTTING POSITIONS FOR SMALLEST AND LARGEST EV
```

```
  150 XMD=MD
      EFFYRS=(XNP-(XMD-1.))/12.0
      P2=(0.5**(1.0/EFFYRS))*100.0
      P1=100.0-P2
  160 FORMAT(1X,21HYEARS (RECORD) MONTHS,5X,18HDURATION IN MONTHS)
      WRITE(6,160)
  170 FORMAT(I5,10X,I5,15X,I3)
      WRITE(6,170)IYEARS,MONTHS,MD
  172 FORMAT(/1X,15HEFFECTIVE YEARS,11X,21HDRAINAGE AREA (SQ MI))
      WRITE(6,172)
  174 FORMAT(F11.2,16X,F10.2)                                    6HEXCEED
      WRITE(6,174)EFFYRS,DA
  180 FORMAT(/3X,6HNUMBER,3X,6HVOLUME,2X,5HDEPTH,6X,4HRATE,2X,6HEXCE
     12X,5HRECUR,2X,6HENDING/13X,5HAC-FT,1X6HINCHES,7X3HCFS,3X,4HFRE
     24X,3HINT,4X,4HDATE)
      WRITE(6,180)                                               4HFREQ
C     ACCUMULATE FLOWS FOR GIVEN DURATION
      ACCUM(1)=FLOW(1)
      DO 220 N=2,MD
  220 ACCUM(N)=ACCUM(N-1)+FLOW(N)
      N=MD+1
      DO 230 N=N,NP
      J=N-MD
  230 ACCUM(N)=ACCUM(N-1)-FLOW(J)+FLOW(N)
      T=MD
      IF(IRUN11-2)231,233,235
C     CONVERT AC-FT TO AVERAGE CFS
  231 DO 232 N=MD,NP
  232 ACCUM(N)=ACCUM(N)*.016598/T
      GO TO 238
C     CONVERT CFS TO AVERAGE CFS
  233 DO 234 N=MD,NP
  234 ACCUM(N)=ACCUM(N)/T
      GO TO 238
C     CONVERT INCHES RUNOFF TO AVERAGE CFS
  235 DO 236 N=MD,NP
  236 ACCUM(N)=ACCUM(N)*DA*.86523/T
  238 NLFF=NP/MD
      IF(NLFF-((NP/12)/2))250,250,240
  240 NLFF=((NP/12)/2)+1
C     DETERMINE FLOW PERIODS IN ASCENDING ORDER AND PRINT
  250 DO 380 I=1,NLFF
      LVP=I1+MD
      VOLUME=ACCUM(LVP)
      J=LVP+1
      DO 270 N=J,NP
      IF(ACCUM(N)-VOLUME)260,270,270
  260 VOLUME=ACCUM(N)
      LVP=N
  270 CONTINUE
      IF(VOLUME-9999999.)275,274,274
  272 FORMAT (29H INDEPENDENT EVENTS EXHAUSTED)
```

```
  274 WRITE(6,272)
      GO TO 390
C     ASSIGN LARGE NUMBERS TO ADJACENT ACCUMULATIVE FLOW VOLUMES
  275 N=LVP-MD+1
      J=LVP+MD-1
      IF(J-NP)290,290,280
  280 J=NP
  290 DO 300 N=N,J
  300 ACCUM(N)=9999999.
C     COMPUTE BEARDS PLOTTING POSITION (FREQUENCY)
      IF(I-1)310,310,320
  310 BPP=P1
      GO TO 330
  320 EVENT=I
      BPP=P2-(((EFFYRS-EVENT)/(EFFYRS-1.))*(P2-P1))
      IF(BPP-60.0)330,330,390
C     COMPUTE DATE OF EVENT
  330 LVP=LVP+M1-1
      IF(LVP-12)340,340,350
  340 IYEAR=IYR1
      MOE=LVP
      GO TO 370
  350 XLVP=LVP
      YEARS=(XLVP/12.0)-.001
      J=YEARS
      IYEAR=J+IYR1
      MOE=LVP-J*12
  370 RATE=VOLUME
      VOL=RATE *60.373*T
      DEPTH=(VOL*.01875)/DA
      RI=100./BPP
  375 FORMAT (I6,F12.0,F7.2,F10.1,F8.2,F7.1,I4,I5)
      WRITE (6,375) I,VOL,DEPTH,RATE,BPP,RI,MOE,IYEAR
  380 CONTINUE
  385 FORMAT (1H1)
  390 WRITE(6,385)
      GO TO 130
  400 GO TO 112
  500 CALL SPOOL(6)
      CALL CLOSE(5)
      CALL CLOSE(6)
      STOP 'CH045 RUN COMPLETED'
      END
```

LISTING OF CORRECTED MONTHLY INPUT DATA

RED LAKE RIVER
AT E. GRAND FORKS

175.0	209.0	874.0	564.0	1,042.0	1,106.0	1930
1,035.0	999.0	379.0	6.0	6.0	6.0	
77.0	147.0	94.0	11.0	58.0	6.0	1931
103.0	24.0	6.0	6.0	6.0	6.0	
6.0	6.0	6.0	6.0	17.0	6.0	
244.0	6.0	6.0	6.0	8.0	6.0	
6.0	6.0	6.0	6.0	6.0	6.0	
141.0	79.0	6.0	6.0	15.0	6.0	
6.0	6.0	6.0	6.0	6.0	42.0	
249.0	84.6	6.0	6.0	16.0	6.0	
6.0	6.0	6.0	6.0	6.0	212.0	1935
81.0	15.0	54.0	6.0	6.0	14.0	
6.0	6.0	6.0	6.0	6.0	6.0	
521.0	6.0	6.0	6.0	2.0	1.0	
6.0	6.0	6.0	6.0	6.0	6.0	
6.0	6.0	6.0	6.0	484.0	6.0	
79.0	6.0	6.0	6.0	23.0	90.0	
6.0	3,217.0	146.0	6.0	6.0	6.0	
106.0	6.0	51.0	8.0	6.0	83.0	
554.0	227.0	6.0	6.0	10.0	136.0	
236.0	6.0	142.0	6.0	6.0	69.0	1940
317.0	6.0	291.0	115.0	45.0	86.0	
168.0	168.0	6.0	6.0	30.0	40.0	
1,442.0	6.0	1,304.0	1,323.0	656.0	1,277.0	
1,326.0	1,105.0	1,011.0	895.0	1,006.0	1,953.0	
1,980.0	2,079.0	739.0	6.0	1,051.0	997.0	
715.0	484.0	976.0	949.0	1,059.0	1,291.0	
1,484.0	1,626.0	1,439.0	1,271.0	1,746.0	1,780.0	
1,705.0	1,436.0	1,036.0	1,474.0	1,037.0	1,324.0	
676.0	394.0	1,501.0	1,065.0	1,147.0	1,311.0	
1,677.0	1,763.0	1,821.0	1,470.0	1,595.0	2,106.0	1945
2,073.0	1,800.0	1,631.0	1,055.0	1,459.0	1,705.0	
1,417.0	1,649.0	1,494.0	1,496.0	1,236.0	2,568.0	
1,513.0	894.0	1,534.0	983.0	1,263.0	1,374.0	
1,436.0	1,499.0	1,227.0	1,422.0	1,232.0	1,379.0	
1,074.0	1,169.0	2,646.0	1,769.0	1,814.0	1,955.0	
1,071.0	1,803.0	1,609.0	1,620.0	1,377.0	1,616.0	1948
4,056.0	1,978.0	1,953.0	1,613.0	1,336.0	530.0	

Note: Monthly flows provided by HEC-3 output have been corrected by adding 3 cfs (EGF) year 2030 withdrawal).

(continued)

366.0	310.0	196.0	270.0	822.0	1,031.0	
1,162.0	871.0	1,510.0	764.0	813.0	1,798.0	1949
1,483.0	1,397.0	1,499.0	1,614.0	1,462.0	1,748.0	
3,231.0	9,146.0	2,182.0	2,446.0	1,953.0	1,953.0	1950
2,078.0	1,953.0	1,953.0	1,953.0	1,953.0	1,953.0	
2,071.0	1,470.0	1,953.0	1,953.0	1,322.0	1,549.0	
1,303.0	993.0	1,270.0	1,953.0	1,953.0	1,900.0	
2,544.0	1,518.0	995.0	1,111.0	1,381.0	1,500.0	
1,348.0	1,237.0	1,178.0	1,156.0	1,294.0	1,182.0	
809.0	871.0	787.0	505.0	1,305.0	1,304.0	
1,064.0	1,263.0	1,031.0	997.0	1,107.0	1,272.0	
1,651.0	987.0	1,363.0	1,570.0	1,331.0	1,256.0	
1,252.0	1,309.0	1,039.0	1,266.0	1,134.0	1,017.0	
559.0	998.0	1,134.0	1,398.0	1,211.6	1,199.0	1955
772.0	823.0	772.0	853.0	713.0	806.0	
1,778.0	2,353.0	680.0	1,232.0	1,272.0	1,234.0	
175.0	767.0	1,016.0	804.0	842.0	998.0	
2,496.0	1,262.0	1,965.0	2,429.0	1,953.0	1,720.0	
1,953.0	1,357.0	1,683.0	1,680.0	1,702.0	1,917.0	
999.0	998.0	1,323.0	1,471.0	1,322.0	820.0	
6.0	993.0	926.0	487.0	551.0	628.0	
30.0	708.0	940.0	167.0	89.0	81.0	
117.0	6.0	6.0	41.0	32.0	13.0	
957.0	724.0	574.0	194.0	6.0	25.0	1960
77.0	54.0	6.0	6.0	449.0	823.0	
6.0	953.0	995.0	983.0	986.0	1,073.0	
994.0	814.0	741.0	981.0	993.0	759.0	
1,017.0	250.0	5,646.0	2,890.0	627.0	1,953.0	
1,953.0	1,953.0	1,621.0	1,935.0	1,806.0	1,387.6	
2,088.0	654.0	343.0	1,953.0	1,560.0	1,760.0	
1,953.0	1,550.0	1,202.0	1,500.0	1,112.0	998.0	
1,761.0	1,276.0	761.0	1,511.0	1,577.0	6.0	
732.0	741.0	639.0	1,080.0	1,090.0	1,203.0	
4,681.0	512.0	2,048.0	1,813.0	1,684.0	1,824.0	1965
1,875.0	1,779.0	1,858.0	1,900.0	1,565.0	224.0	
5,466.0	2,015.6	1,779.0	1,953.0	1,092.0	1,953.0	
1,953.0	1,953.0	1,953.0	1,793.0	1,522.0	1,953.0	
1,592.0	3,984.0	1,912.0	1,758.0	1,570.0	1,012.0	

1,355.0	1,191.0	1,300.0	993.0	993.0	1,243.0	
[illegible]	996.0	487.0	3,506.0	934.0	1,631.0	
1,386.0	1,620.0	1,800.0	1,250.0	1,227.0	1,830.0	1969
1,389.0	621.0	970.0	1,953.0	986.0	1,310.0	
1,953.0	1,953.0	993.0	1,953.0	1,953.0	1,953.0	1970
3,866.0	1,975.0	3,692.0	1,953.0	1,290.0	1,953.0	
994.0	1,950.0	1,798.0	1,781.0	1,868.0	1,799.0	
2,524.0	1,953.0	1,938.0	1,387.0	986.0	1,582.0	
684.0	3.0	1,953.0	1,905.0	1,926.0	1,902.0	
4,986.0	1,879.0	1,670.0	983.0	1,953.0	1,953.0	
882.0	993.0	1,670.0	1,607.0	1,610.0	1,364.0	
995.0	998.0	1,418.0	983.0	2,443.0	20,218.0	
1,839.0	1,416.0	1,768.0	1,934.0	1,953.0	1,028.0	
7,233.0	9,861.0	2,193.0	1,953.0	2,341.0	1,953.0	
1,944.0	1,707.0	1,915.0	1,953.0	1,922.0	998.0	1975
6,663.0	7,729.0	4,736.0	7,463.0	1,811.0	1,953.0	
1,553.0	1,953.0	1,953.0	1,953.0	1,953.0	709.0	1976
1,143.0	1,953.0	1,366.0	983.0	1,046.0	1,669.0	

(continued)

RED RIVER OF THE NORTH
AT GRAND FORKS, N.D.

LISTING OF CORRECTED MONTHLY INPUT DATA

305.0	542.0	1,165.0	625.0	1,364.0	4,739.0	1930
3,206.0	2,728.0	857.0	337.0	46.0	97.0	
114.0	249.0	202.0	216.0	353.0	614.0	1931
862.0	443.0	423.0	211.0	98.0	99.0	
145.0	226.0	184.0	218.0	273.0	1,257.0	1932
3,765.0	994.0	415.0	160.0	40.0	79.0	
63.0	116.0	147.0	157.0	145.0	1,051.0	
2,151.0	858.0	507.0	66.0	38.0	70.0	
105.0	154.0	120.0	86.0	85.0	496.0	
1,522.0	363.0	143.0	133.0	38.0	79.0	
112.0	139.0	103.0	86.0	81.0	1,180.0	1935
1,434.0	957.0	609.0	726.0	329.0	221.0	
183.0	162.0	147.0	86.0	85.0	316.0	
5,767.0	1,753.0	333.0	65.0	31.0	73.0	
75.0	97.0	84.0	71.0	58.0	90.0	
1,384.0	1,938.0	1,022.0	740.0	1,295.0	817.0	
355.0	247.0	73.0	85.0	93.0	1,563.0	
843.0	5,320.0	2,157.0	571.0	51.0	111.0	
134.0	120.0	119.0	158.0	153.0	761.0	
3,146.0	731.0	508.0	174.0	38.0	122.0	
185.0	185.0	131.0	48.0	45.0	134.0	1940
4,024.0	1,751.0	643.0	71.0	84.0	93.0	
152.0	219.0	152.0	191.0	205.0	377.0	
7,149.0	2,380.0	5,000.0	1,711.0	1,060.0	2,397.0	
2,503.0	1,550.0	1,276.0	858.0	868.0	1,685.0	
4,780.0	6,957.0	3,714.0	1,571.0	1,969.0	3,356.0	
1,686.0	1,564.0	1,381.0	1,393.0	1,501.0	1,836.0	
20,826.0	6,175.0	11,980.0	4,873.0	2,793.0	2,117.0	
1,891.0	1,800.0	1,557.0	1,309.0	1,283.0	1,262.0	
2,788.0	3,833.0	5,293.0	6,018.0	5,612.0	4,445.0	
3,115.0	2,711.0	2,150.0	1,825.0	1,842.0	10,115.0	1945
12,838.0	5,626.0	3,549.0	1,876.0	1,431.0	1,954.0	
2,447.0	1,910.0	1,594.0	1,471.0	1,429.0	6,788.0	
9,436.0	3,718.0	2,545.0	2,894.0	1,795.0	1,968.0	
2,725.0	2,306.0	1,896.0	1,839.0	1,647.0	2,099.0	
21,188.0	7,681.0	10,006.0	3,331.0	1,619.0	1,686.0	

NOTE: Monthly flows provided by HEC-3 output have been corrected by adding 30 cfs (the municipal withdrawals assumed extracted at Grand Forks and returned at some downstream point).

(continued)

1,956.0	1,833.0	1,694.0	1,583.0	1,456.0	1,510.0	
20,399.0	7,251.0	2,751.0	2,054.0	1,631.0	507.0	
389.0	474.0	369.0	321.0	915.0	1,250.0	
6,416.0	3,282.0	4,753.0	3,919.0	3,085.0	1,935.0	
1,256.0	1,826.0	1,766.0	1,449.0	1,391.0	1,886.0	1950
27,720.0	30,042.0	10,131.0	6,404.0	2,120.0	871.0	
963.0	1,083.0	1,054.0	1,350.0	1,330.0	1,719.0	
14,918.0	7,430.0	3,228.0	2,166.0	1,654.0	2,088.0	
2,149.0	1,973.0	2,344.0	1,848.0	1,883.0	2,110.0	
19,683.0	4,873.0	3,195.0	5,263.0	2,510.0	1,853.0	
1,397.0	1,481.0	1,359.0	1,278.0	1,338.0	3,071.0	
3,640.0	3,836.0	10,168.0	4,601.0	3,025.0	2,109.0	
1,890.0	1,943.0	1,771.0	1,663.0	1,858.0	2,578.0	
5,308.0	3,974.0	3,632.0	2,601.0	1,554.0	1,456.0	
1,706.0	1,518.0	1,407.0	1,391.0	1,473.0	1,416.0	1955
6,004.0	2,894.0	2,931.0	3,203.0	2,677.0	1,584.0	
1,471.0	1,338.0	981.0	1,234.0	1,077.0	1,184.0	
10,420.0	5,458.0	2,888.0	2,009.0	1,468.0	1,290.0	
443.0	1,131.0	1,203.0	1,037.0	1,079.0	2,551.0	
4,922.0	3,473.0	4,359.0	4,642.0	2,028.0	3,733.0	
2,842.0	2,992.0	2,100.0	1,668.0	1,733.0	2,170.0	
3,031.0	2,265.0	2,297.0	3,941.0	1,637.0	1,274.0	
480.0	1,644.0	1,375.0	837.0	904.0	1,698.0	
3,129.0	2,665.0	3,867.0	2,199.0	703.0	507.0	
512.0	390.0	396.0	506.0	508.0	619.0	1960
9,834.0	3,808.0	3,531.0	1,846.0	509.0	733.0	
471.0	558.0	441.0	376.0	819.0	2,487.0	
1,842.0	3,781.0	1,988.0	1,319.0	1,156.0	1,260.0	
1,514.0	1,153.0	943.0	1,147.0	1,314.0	1,030.0	
11,922.0	12,082.0	22,744.0	15,006.0	5,038.0	2,691.0	
1,872.0	2,045.0	1,826.0	1,377.0	1,289.0	1,479.0	
5,262.0	3,322.0	6,663.0	2,646.0	1,583.0	1,549.0	
1,511.0	1,437.0	1,215.0	1,291.0	1,432.0	1,581.0	
7,667.0	4,912.0	4,957.0	2,729.0	1,880.0	770.0	
1,506.0	907.0	466.0	914.0	1,133.0	1,238.0	1965
27,565.0	8,751.0	8,714.0	3,693.0	2,270.0	2,174.0	
3,368.0	2,596.0	2,364.0	1,958.0	1,905.0	12,680.0	
26,983.0	10,971.0	4,293.0	2,772.0	3,604.0	1,950.0	

1,973.0	1,997.0	1,354.0	1,892.0	1,670.0	3,073.0	
18,766.0	9,557.0	6,254.0	3,439.0	1,522.0	1,173.0	
1,459.0	1,498.0	1,589.0	1,446.0	1,436.0	2,473.0	
3,048.0	3,190.0	4,301.0	3,755.0	1,964.0	1,864.0	
2,228.0	2,158.0	1,788.0	1,492.0	1,580.0	1,939.0	
34,161.0	12,262.0	3,652.0	3,404.0	1,751.0	1,486.0	
1,297.0	1,432.0	1,721.0	1,282.0	1,488.0	1,690.0	1970
15,416.0	8,487.0	9,693.0	2,571.0	2,232.0	1,521.0	
1,648.0	1,848.0	1,456.0	1,465.0	1,411.0	2,650.0	
7,691.0	3,146.0	2,544.0	2,359.0	1,680.0	2,446.0	
4,712.0	5,472.0	3,250.0	1,850.0	1,778.0	10,276.0	
16,761.0	8,784.0	4,012.0	2,469.0	2,396.0	3,241.0	
1,961.0	1,942.0	3,161.0	2,908.0	2,962.0	5,531.0	
2,891.0	2,264.0	1,919.0	1,646.0	3,168.0	24,000.0	
5,647.0	2,583.0	2,041.0	1,846.0	1,669.0	26,397.0	1974
21,779.0	12,876.0	7,954.0	1,907.0	1,964.0	1,078.0	
1,603.0	1,934.0	1,406.0	1,472.0	1,751.0	2,062.0	1975
28,232.0	23,294.0	11,510.0	11,894.0	4,777.0	3,694.0	
1,519.0	1,948.0	1,731.0	1,241.0	1,460.0	[illegible]	1976
9,545.0	2,701.0	[illegible]	1,238.0	1,056.0	1,728.0	

(continued)

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GRAND FORKS - EAST GRAND FORKS URBAN WATER RESOURCES STUDY. WAT--ETC(U)
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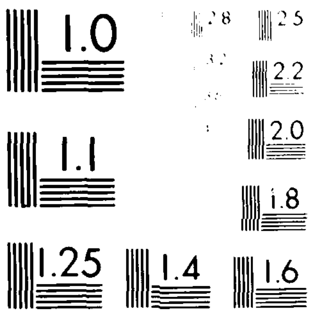


MICROCOPY RESOLUTION TEST CHART

PARTIAL DURATION ANALYSIS WITH GF AND
EGF DEMANDS ADDED BACK INTO THE "RIVER FLOWS"

RED LAKE RIVER AT EAST GRAND FORKS

ARTIAL DURATION
RAND FORKS
ONTHLY FLOWS IN CFS

YEARS (RECORD)	MONTHS	DURATION IN MONTHS
47	0	2

EFFECTIVE YEARS	DRAINAGE AREA (SQ MI)
46.92	5280.00

NUMBER	VOLUME AC-FT	DEPTH INCHES	RATE CFS	EXCEED FREQ	RECUR INT	ENDING DATE
1	362.	0.00	3.0	1.47	68.2	9 1936
2	724.	0.00	6.0	3.58	27.9	8 1930
3	724.	0.00	6.0	5.69	17.6	7 1931
4	724.	0.00	6.0	7.81	12.8	9 1931
5	724.	0.00	6.0	9.92	10.1	11 1931
6	724.	0.00	6.0	12.04	8.3	1 1932
7	724.	0.00	6.0	14.15	7.1	8 1932
8	724.	0.00	6.0	16.26	6.1	10 1932
9	724.	0.00	6.0	18.38	5.4	12 1932
10	724.	0.00	6.0	20.49	4.9	2 1933
11	724.	0.00	6.0	22.61	4.4	7 1933
12	724.	0.00	6.0	24.72	4.0	10 1933
13	724.	0.00	6.0	26.83	3.7	12 1933
14	724.	0.00	6.0	28.95	3.5	2 1934
15	724.	0.00	6.0	31.06	3.2	7 1934
16	724.	0.00	6.0	33.18	3.0	10 1934
17	724.	0.00	6.0	35.29	2.8	12 1934
18	724.	0.00	6.0	37.40	2.7	2 1935
19	724.	0.00	6.0	39.52	2.5	8 1935
20	724.	0.00	6.0	41.63	2.4	11 1935
21	724.	0.00	6.0	43.75	2.3	1 1936
22	724.	0.00	6.0	45.86	2.2	3 1936
23	724.	0.00	6.0	47.97	2.1	6 1936
24	724.	0.00	6.0	50.09	2.0	11 1936

(continued)

EARS (RECORD) MONTHS 47 0 | DURATION IN MONTHS 4

FFECTIVE YEARS 46.75 | DRAINAGE AREA (SQ MI) 5280.00

NUMBER	VOLUME AC-FT	DEPTH INCHES	RATE CFS	EXCEED FREQ	RECUR INT	ENDING DATE
1	1087.	0.00	4.5	1.47	67.9	9 1936
2	1449.	0.01	6.0	3.59	27.8	9 1931
3	1449.	0.01	6.0	5.71	17.5	1 1932
4	1449.	0.01	6.0	7.84	12.8	12 1932
5	1449.	0.01	6.0	9.96	10.0	12 1933
6	1449.	0.01	6.0	12.08	8.3	12 1934
7	1449.	0.01	6.0	14.20	7.0	1 1936
8	1449.	0.01	6.0	16.32	6.1	1 1937
9	1449.	0.01	6.0	18.44	5.4	5 1937
10	1570.	0.01	6.5	20.56	4.9	8 1932
11	2475.	0.01	10.3	22.69	4.4	2 1938
12	4286.	0.02	17.8	24.81	4.0	2 1939
13	4830.	0.02	20.0	26.93	3.7	9 1935
14	4951.	0.02	20.5	29.05	3.4	3 1941
15	5132.	0.02	21.3	31.17	3.2	2 1960
16	5735.	0.02	23.8	33.29	3.0	10 1930
17	6400.	0.02	26.5	35.42	2.8	8 1933
18	6762.	0.02	28.0	37.54	2.7	8 1934
19	7486.	0.03	31.0	39.66	2.5	10 1938
20	8633.	0.03	35.8	41.78	2.4	1 1961
21	9539.	0.03	39.5	43.90	2.3	9 1939
22	9599.	0.03	39.8	46.02	2.2	4 1933
23	9660.	0.03	40.0	48.14	2.1	2 1940
24	10203.	0.04	42.3	50.27	2.0	3 1931

(continued)

YEARS (RECORD) MONTHS 47 0

DURATION IN MONTHS 3

EFFECTIVE YEARS 46.83

DRAINAGE AREA (SQ MI) 5260.00

NUMBER	VOLUME AC-FT	DEPTH INCHES	RATE CFS	EXCEED FREQ	RECUR INT	ENDING DATE
1	724.	0.00	4.0	1.47	68.1	9 1936
2	1087.	0.00	6.0	3.59	27.9	9 1930
3	1087.	0.00	6.0	5.70	17.5	8 1931
4	1087.	0.00	6.0	7.82	12.8	11 1931
5	1087.	0.00	6.0	9.94	10.1	7 1932
6	1087.	0.00	6.0	12.06	8.3	11 1932
7	1087.	0.00	6.0	14.18	7.1	2 1933
8	1087.	0.00	6.0	16.29	6.1	11 1933
9	1087.	0.00	6.0	18.41	5.4	2 1934
10	1087.	0.00	6.0	20.53	4.9	11 1934
11	1087.	0.00	6.0	22.65	4.4	2 1935
12	1087.	0.00	6.0	24.76	4.0	12 1935
13	1087.	0.00	6.0	26.88	3.7	3 1936
14	1087.	0.00	6.0	29.00	3.4	12 1936
15	1087.	0.00	6.0	31.12	3.2	3 1937
16	1087.	0.00	6.0	33.23	3.0	6 1937
17	1087.	0.00	6.0	35.35	2.8	1 1938
18	1087.	0.00	6.0	37.47	2.7	9 1938
19	1328.	0.00	7.3	39.59	2.5	8 1939
20	1570.	0.01	8.7	41.71	2.4	9 1935
21	1630.	0.01	9.0	43.82	2.3	8 1933
22	1690.	0.01	9.3	45.94	2.2	8 1934
23	1751.	0.01	9.7	48.06	2.1	2 1932
24	2536.	0.01	14.0	50.18	2.0	2 1941

(continued)

YEARS (RECORD) MONTHS DURATION IN MONTHS
47 0 6

EFFECTIVE YEARS DRAINAGE AREA (SQ MI)
46.58 5280.00

NUMBER	VOLUME AC-FT	DEPTH INCHES	RATE CFS	EXCEED FREQ	RECUR INT	ENDING DATE
1	1811.	0.01	5.0	1.48	67.7	10 1936
2	2173.	0.01	6.0	3.61	27.7	11 1931
3	2173.	0.01	6.0	5.73	17.4	2 1933
4	2173.	0.01	6.0	7.86	12.7	2 1934
5	2173.	0.01	6.0	9.99	10.0	2 1935
6	2173.	0.01	6.0	12.12	8.2	3 1936
7	2173.	0.01	6.0	14.25	7.0	4 1937
8	7607.	0.03	21.0	16.38	6.1	2 1938
9	10505.	0.04	29.0	18.51	5.4	1 1961
10	10626.	0.04	29.3	20.64	4.8	9 1935
11	10928.	0.04	30.2	22.77	4.4	12 1938
12	12980.	0.05	35.8	24.90	4.0	3 1960
13	15274.	0.05	42.2	27.02	3.7	8 1933
14	16663.	0.06	46.0	29.15	3.4	8 1932
15	17870.	0.06	49.3	31.28	3.2	5 1931
16	24149.	0.09	66.7	33.41	3.0	11 1939
17	24330.	0.09	67.2	35.54	2.8	8 1934
18	25236.	0.09	69.7	37.67	2.7	3 1941
19	32964.	0.12	91.0	39.80	2.5	5 1940
20	37492.	0.13	103.5	41.93	2.4	11 1930
21	121652.	0.43	335.8	44.06	2.3	9 1959
22	150570.	0.53	415.7	46.19	2.2	2 1949
23	216739.	0.77	598.3	48.31	2.1	11 1942
24	216799.	0.77	598.5	50.44	2.0	3 1959

(continued)

EARS (RECORD)	MONTHS	DURATION IN MONTHS
47	0	9

EFFECTIVE YEARS	DRAINAGE AREA (SQ MI)
46.33	5280.00

NUMBER	VOLUME AC-FT	DEPTH INCHES	RATE CFS	EXCEED FREQ	RECUR INT	ENDING DATE
1	2898.	0.01	5.3	1.48	67.3	1 1937
2	3381.	0.01	6.2	3.63	27.6	1 1933
3	3743.	0.01	6.9	5.77	17.3	3 1936
4	3803.	0.01	7.0	7.91	12.6	2 1934
5	3864.	0.01	7.1	10.05	10.0	2 1935
6	3924.	0.01	7.2	12.19	8.2	2 1932
7	16764.	0.06	30.9	14.33	7.0	3 1939
8	24813.	0.09	45.7	16.47	6.1	3 1931
9	33326.	0.12	61.3	18.61	5.4	3 1960
10	33447.	0.12	61.6	20.75	4.8	2 1940
11	36526.	0.13	67.2	22.89	4.4	10 1937
12	40086.	0.14	73.8	25.03	4.0	3 1941
13	83979.	0.30	154.6	27.17	3.7	2 1961
14	310861.	1.10	572.1	29.31	3.4	5 1959
15	335553.	1.19	617.6	31.45	3.2	5 1949
16	385361.	1.37	709.2	33.59	3.0	6 1930
17	396892.	1.41	730.4	35.73	2.8	2 1943
18	455514.	1.62	838.3	37.87	2.6	12 1961
19	484312.	1.72	891.3	40.01	2.5	2 1957
20	491255.	1.74	904.1	42.15	2.4	2 1965
21	516008.	1.83	949.7	44.29	2.3	3 1956
22	534644.	1.90	984.3	46.43	2.2	12 1953
23	537501.	1.91	989.2	48.57	2.1	1 1942
24	537501.	1.91	989.2	50.71	2.0	6 1968

(continued)

ARS (RECORD) MONTHS 47 0

DURATION IN MONTHS 12

FECTIVE YEARS 46.08

DRAINAGE AREA (SQ MI) 5280.00

NUMBER	VOLUME AC-FT	DEPTH INCHES	RATE CFS	EXCEED FREQ	RECUR INT	ENDING DATE
1	3985.	0.01	5.5	1.49	67.0	4 1937
2	11954.	0.04	16.5	3.64	27.4	2 1932
3	12618.	0.04	17.4	5.80	17.3	4 1933
4	12799.	0.05	17.7	7.95	12.6	3 1936
5	26142.	0.09	36.1	10.10	9.9	4 1934
6	43710.	0.16	60.3	12.25	8.2	4 1938
7	57113.	0.20	78.8	14.40	6.9	5 1940
8	72749.	0.26	100.4	16.56	6.0	5 1939
9	134632.	0.48	185.8	18.71	5.3	3 1960
10	145197.	0.52	200.4	20.86	4.8	5 1941
11	177738.	0.63	245.3	23.01	4.3	4 1961
12	236904.	0.84	327.0	25.16	4.0	2 1931
13	521925.	1.85	720.4	27.32	3.7	8 1949
14	629932.	2.24	869.5	29.47	3.4	3 1959
15	639109.	2.27	882.2	31.62	3.2	5 1962
16	674668.	2.40	931.3	33.77	3.0	5 1943
17	678472.	2.41	936.5	35.92	2.8	3 1956
18	733230.	2.60	1012.1	38.07	2.6	2 1954
19	734860.	2.61	1014.3	40.23	2.5	2 1965
20	770843.	2.74	1064.0	42.38	2.4	5 1957
21	799520.	2.84	1103.6	44.53	2.2	6 1968
22	850052.	3.02	1173.3	46.68	2.1	10 1944
23	916160.	3.25	1264.6	48.83	2.0	3 1955
24	924733.	3.28	1276.4	50.99	2.0	4 1947

(continued)

ARS (RECORD) MONTHS 47 0

DURATION IN MONTHS 24

FECTIVE YEARS 45.08

DRAINAGE AREA (SQ MI) 5280.00

NUMBER	VOLUME AC-FT	DEPTH INCHES	RATE CFS	EXCEED FREQ	RECUR INT	ENDING DATE
1	30790.	0.11	21.3	1.53	65.5	2 1933
2	39907.	0.14	27.5	3.72	26.8	6 1937
3	43952.	0.16	30.3	5.92	16.9	2 1935
4	129862.	0.46	89.6	8.12	12.3	5 1940
5	358012.	1.27	247.1	10.32	9.7	2 1961
6	1106033.	3.93	763.3	12.52	8.0	5 1942
7	1472437.	5.23	1016.2	14.72	6.8	3 1957
8	1603990.	5.70	1107.0	16.92	5.9	5 1944
9	1645466.	5.84	1135.6	19.12	5.2	5 1954
10	1753353.	6.23	1210.1	21.32	4.7	3 1965
11	1796520.	6.38	1239.9	23.52	4.3	4 1950
12	1890158.	6.71	1304.5	25.72	3.9	8 1969
13	1977337.	7.02	1364.7	27.92	3.6	2 1963
14	2034993.	7.23	1404.5	30.12	3.3	5 1947
15	2225590.	7.90	1536.0	32.31	3.1	7 1973
16	2659974.	9.45	1835.8	34.51	2.9	4 1967
17	2664200.	9.46	1838.7	36.71	2.7	5 1952
18	3588149.	12.74	2476.4	38.91	2.6	9 1976

INDEPENDENT EVENTS EXHAUSTED

(continued)

YEARS (RECORD) MONTHS DURATION IN MONTHS
47 0 48

EFFECTIVE YEARS DRAINAGE AREA (SQ MI)
43.08 5280.00

NUMBER	VOLUME AC-FT	DEPTH INCHES	RATE CFS	EXCEED FREQ	RECUR INT	ENDING DATE
1	74742.	0.27	25.8	1.60	62.7	2 1935
2	317803.	1.13	109.7	3.90	25.7	3 1939
3	1576158.	5.60	543.9	6.20	16.1	5 1962
4	1685131.	5.98	581.5	8.50	11.8	3 1943
5	3127261.	11.11	1079.1	10.80	9.3	3 1957
6	4024827.	14.29	1388.9	13.10	7.6	3 1950
7	4543250.	16.13	1567.8	15.40	6.5	7 1966
8	4594023.	16.31	1585.3	17.70	5.7	11 1971
9	7808946.	27.73	2694.7	20.00	5.0	9 1976

INDEPENDENT EVENTS EXHAUSTED

YEARS (RECORD) MONTHS DURATION IN MONTHS
47 0 96

EFFECTIVE YEARS DRAINAGE AREA (SQ MI)
39.08 5280.00

NUMBER	VOLUME AC-FT	DEPTH INCHES	RATE CFS	EXCEED FREQ	RECUR INT	ENDING DATE
1	287134.	1.02	49.5	1.76	56.9	4 1938
2	5101761.	18.12	880.3	4.29	23.3	5 1946
3	5260722.	18.68	907.7	6.82	14.7	5 1962
4	8936411.	31.73	1541.9	9.36	10.7	5 1954
5	9346043.	33.19	1612.6	11.89	8.4	11 1971

PARTIAL DURATION ANALYSIS WITH CF AND EGF DEMANDS ADDED BACK INTO THE "RIVER FLOWS"

RED RIVER OF THE NORTH AT GRAND FORKS

ARTIAL DURATION
RAND FORKS
ONTHLY FLOWS IN CFS

YEARS (RECORD)	MONTHS	DURATION IN MONTHS
47	0	2

EFFECTIVE YEARS	DRAINAGE AREA (SQ MI)
46.92	30100.00

NUMBER	VOLUME AC-FT	DEPTH INCHES	RATE CFS	EXCEED FREQ	RECUR INT	ENDING DATE
1	5615.	0.00	46.5	1.47	68.2	2 1940
2	5796.	0.00	48.0	3.58	27.9	8 1936
3	6279.	0.00	52.0	5.69	17.6	8 1933
4	7064.	0.00	58.5	7.81	12.8	9 1934
5	7184.	0.00	59.5	9.92	10.1	9 1932
6	7788.	0.00	64.5	12.04	8.3	2 1937
7	8633.	0.01	71.5	14.15	7.1	9 1930
8	8935.	0.01	74.0	16.26	6.1	10 1936
9	9358.	0.01	77.5	18.36	5.4	8 1940
10	9539.	0.01	79.0	20.49	4.9	1 1938
11	9660.	0.01	80.0	22.61	4.4	9 1939
12	9780.	0.01	81.0	24.72	4.0	9 1938
13	10082.	0.01	83.5	26.83	3.7	2 1935
14	10324.	0.01	85.5	28.95	3.5	2 1934
15	10324.	0.01	85.5	31.06	3.2	2 1936
16	10565.	0.01	87.5	33.18	3.0	10 1933
17	10807.	0.01	89.5	35.29	2.8	11 1932
18	10928.	0.01	90.5	37.40	2.7	12 1936
19	11410.	0.01	94.5	39.52	2.5	9 1931
20	14429.	0.01	119.5	41.63	2.4	12 1938
21	14610.	0.01	121.0	43.75	2.3	12 1934
22	14791.	0.01	122.5	45.86	2.2	10 1940
23	16542.	0.01	137.0	47.97	2.1	12 1933
24	16663.	0.01	138.0	50.09	2.0	7 1934

(continued)

YEARS (RECORD)	MONTHS	DURATION IN MONTHS
47	0	3

EFFECTIVE YEARS	DRAINAGE AREA (SQ MI)
46.83	30100.00

NUMBER	VOLUME AC-FT	DEPTH INCHES	RATE CFS	EXCEED FREQ	RECUR INT	ENDING DATE
1	10203.	0.01	56.3	1.47	68.1	9 1936
2	10505.	0.01	58.0	3.59	27.9	9 1933
3	10988.	0.01	60.7	5.70	17.5	10 1932
4	12859.	0.01	71.0	7.82	12.8	2 1937
5	13524.	0.01	74.7	9.94	10.1	2 1940
6	13825.	0.01	76.3	12.06	8.3	10 1934
7	14973.	0.01	82.7	14.18	7.1	9 1940
8	15154.	0.01	83.7	16.29	6.1	2 1938
9	15516.	0.01	85.7	18.41	5.4	10 1930
10	16301.	0.01	90.0	20.53	4.9	2 1935
11	17569.	0.01	97.0	22.65	4.4	2 1934
12	17870.	0.01	98.7	24.76	4.0	10 1938
13	19199.	0.01	106.0	26.88	3.7	2 1936
14	20165.	0.01	111.3	29.00	3.4	10 1931
15	20165.	0.01	111.3	31.12	3.2	9 1939
16	23968.	0.01	132.3	33.23	3.0	1 1939
17	25357.	0.02	140.0	35.35	2.8	1 1933
18	31575.	0.02	174.3	37.47	2.7	12 1940
19	34171.	0.02	188.7	39.59	2.5	11 1935
20	37914.	0.02	209.3	41.71	2.4	1 1932
21	38578.	0.02	213.0	43.82	2.3	7 1934
22	40269.	0.03	222.3	45.94	2.2	1 1931
23	46668.	0.03	257.7	48.06	2.1	3 1941
24	65022.	0.04	359.0	50.18	2.0	7 1931

(continued)

YEARS (RECORD) MONTHS 47 0

DURATION IN MONTHS 4

EFFECTIVE YEARS 46.75

DRAINAGE AREA (SQ MI) 30100.00

NUMBER	VOLUME AC-FT	DEPTH INCHES	RATE CFS	EXCEED FREQ	RECUR INT	ENDING DATE
1	14731.	0.01	61.0	1.47	67.9	10 1936
2	16844.	0.01	69.8	3.59	27.8	10 1933
3	17991.	0.01	74.5	5.71	17.5	11 1932
4	18293.	0.01	75.8	7.84	12.8	3 1937
5	21614.	0.01	89.5	9.96	10.0	3 1940
6	21855.	0.01	90.5	12.08	8.3	10 1934
7	24149.	0.02	100.0	14.20	7.0	10 1940
8	24693.	0.02	102.3	16.32	6.1	2 1935
9	25115.	0.02	104.0	18.44	5.4	11 1938
10	26866.	0.02	111.3	20.56	4.9	2 1934
11	28979.	0.02	120.0	22.69	4.4	2 1936
12	30066.	0.02	124.5	24.81	4.0	2 1938
13	30549.	0.02	126.5	26.93	3.7	11 1930
14	31334.	0.02	129.8	29.05	3.4	10 1939
15	32903.	0.02	136.3	31.17	3.2	10 1931
16	46306.	0.03	191.8	33.29	3.0	2 1941
17	54396.	0.03	225.3	35.42	2.8	2 1932
18	71904.	0.04	297.8	37.54	2.7	3 1939
19	83617.	0.05	346.3	39.66	2.5	3 1931
20	88084.	0.05	364.8	41.78	2.4	10 1935
21	90560.	0.06	375.0	43.90	2.3	3 1933
22	93759.	0.06	388.3	46.02	2.2	1 1949
23	108671.	0.07	450.0	48.14	2.1	2 1960
24	111449.	0.07	461.5	50.27	2.0	1 1961

(continued)

YEARS (RECORD) MONTHS 47 0

DURATION IN MONTHS 6

EFFECTIVE YEARS 46.58

DRAINAGE AREA (SQ MI) 30100.00

NUMBER	VOLUME AC-FT	DEPTH INCHES	RATE CFS	EXCEED FREQ	RECUR INT	ENDING DATE
1	25659.	0.02	70.8	1.48	67.7	12 1936
2	33386.	0.02	92.2	3.61	27.7	12 1933
3	33628.	0.02	92.8	5.73	17.4	1 1935
4	36345.	0.02	100.3	7.86	12.7	1 1933
5	41836.	0.03	115.5	9.99	10.0	1 1939
6	42804.	0.03	118.2	12.12	8.2	1 1940
7	46548.	0.03	128.5	14.25	7.0	12 1940
8	53370.	0.03	147.3	16.38	6.1	2 1936
9	55785.	0.03	154.0	18.51	5.4	1 1931
10	57656.	0.04	159.2	20.64	4.8	12 1931
11	100823.	0.06	278.3	22.77	4.4	2 1936
12	162705.	0.10	449.2	24.90	4.0	6 1934
13	170191.	0.11	469.8	27.02	3.7	2 1960
14	179610.	0.11	495.8	29.15	3.4	2 1949
15	186432.	0.12	514.7	31.28	3.2	1 1961
16	275482.	0.17	760.5	33.41	3.0	6 1937
17	301080.	0.19	831.2	35.54	2.8	7 1935
18	330421.	0.21	912.2	37.67	2.7	7 1939
19	343885.	0.21	949.3	39.80	2.5	2 1965
20	373286.	0.23	1030.5	41.93	2.4	2 1957
21	393270.	0.24	1085.7	44.06	2.3	2 1959
22	401541.	0.25	1108.5	46.19	2.2	2 1951
23	414400.	0.26	1144.0	48.31	2.1	7 1932
24	428709.	0.27	1183.5	50.44	2.0	3 1962

(continued)

YEARS (RECORD)	MONTHS	DURATION IN MONTHS
47	0	9

EFFECTIVE YEARS	DRAINAGE AREA (SQ MI)
46.33	30100.00

NUMBER	VOLUME AC-FT	DEPTH INCHES	RATE CFS	EXCEED FREQ	RECUR INT	ENDING DATE
1	38880.	0.02	71.6	1.48	67.3	3 1937
2	55161.	0.03	101.6	3.63	27.6	2 1935
3	64116.	0.04	118.0	5.77	17.3	3 1940
4	73655.	0.05	135.6	7.91	12.6	3 1934
5	79813.	0.05	146.9	10.05	10.0	2 1933
6	93216.	0.06	171.6	12.19	8.2	3 1941
7	112837.	0.07	207.7	14.33	7.0	2 1932
8	131492.	0.08	242.0	16.47	6.1	3 1939
9	134511.	0.08	247.6	18.61	5.4	3 1931
10	136141.	0.08	250.6	20.75	4.8	3 1936
11	265383.	0.16	525.2	22.89	4.4	2 1938
12	382765.	0.24	704.4	25.03	4.0	3 1960
13	477550.	0.30	878.9	27.17	3.7	3 1949
14	497232.	0.31	915.1	29.31	3.4	4 1961
15	654202.	0.41	1204.0	31.45	3.2	3 1962
16	692056.	0.43	1273.7	33.59	3.0	3 1965
17	737215.	0.46	1356.8	35.73	2.8	3 1957
18	783521.	0.49	1442.0	37.87	2.6	4 1959
19	839668.	0.52	1545.3	40.01	2.5	3 1942
20	860013.	0.54	1582.8	42.15	2.4	3 1964
21	876858.	0.55	1613.8	44.29	2.3	3 1955
22	890441.	0.55	1638.8	46.43	2.2	3 1956
23	916281.	0.57	1686.3	48.57	2.1	3 1975
24	937653.	0.58	1725.7	50.71	2.0	6 1930

(continued)

YEARS (RECORD)	MONTHS	DURATION IN MONTHS
47	0	12

EFFECTIVE YEARS	DRAINAGE AREA (SQ MI)
46.08	30100.00

NUMBER	VOLUME AC-FT	DEPTH INCHES	RATE CFS	EXCEED FREQ	RECUR INT	ENDING DATE
1	196092.	0.12	270.7	1.49	67.0	6 1934
2	228693.	0.14	315.7	3.64	27.4	2 1932
3	248375.	0.15	342.8	5.80	17.3	4 1937
4	298907.	0.19	412.6	7.95	12.6	6 1935
5	324928.	0.20	448.5	10.10	9.9	5 1933
6	328852.	0.20	453.9	12.25	8.2	3 1940
7	480690.	0.30	663.5	14.40	6.9	3 1941
8	547644.	0.34	755.9	16.56	6.0	4 1938
9	793543.	0.49	1095.3	18.71	5.3	2 1931
10	925156.	0.58	1277.0	20.86	4.8	7 1961
11	966028.	0.60	1333.4	23.01	4.3	3 1960
12	1229134.	0.77	1696.6	25.16	4.0	5 1949
13	1293975.	0.81	1786.1	27.32	3.7	3 1959
14	1418403.	0.88	1957.8	29.47	3.4	5 1957
15	1573803.	0.98	2172.3	31.62	3.2	4 1942
16	1591010.	0.99	2196.1	33.77	3.0	6 1955
17	1622464.	1.01	2239.5	35.92	2.8	6 1968
18	1750757.	1.09	2416.6	38.07	2.6	3 1965
19	1765729.	1.10	2437.3	40.23	2.5	1 1964
20	1776113.	1.11	2451.6	42.38	2.4	8 1971
21	1800685.	1.12	2485.5	44.53	2.2	9 1976
22	1824533.	1.14	2518.4	46.68	2.1	5 1953
23	1859428.	1.16	2566.6	48.83	2.0	6 1944
24	1981563.	1.23	2735.2	50.99	2.0	7 1973

(continued)

YEARS (RECORD)	MONTHS	DURATION IN MONTHS
47	0	24

EFFECTIVE YEARS	DRAINAGE AREA (SQ MI)
45.06	30100.00

NUMBER	VOLUME AC-FT	DEPTH INCHES	RATE CFS	EXCEED FREQ	RECUR INT	ENDING DATE
1	482863.	0.30	333.3	1.53	65.5	4 1935
2	671710.	0.42	463.6	3.72	26.8	2 1933
3	796018.	0.50	549.4	5.92	16.9	4 1938
4	809542.	0.50	558.7	8.12	12.3	3 1941
5	2260003.	1.41	1559.8	10.32	9.7	3 1960
6	2647960.	1.65	1827.5	12.52	8.0	3 1962
7	3261108.	2.03	2250.7	14.72	6.8	3 1956
8	3531277.	2.20	2437.1	16.92	5.9	3 1965
9	3631135.	2.26	2506.0	19.12	5.2	3 1943
10	4083570.	2.54	2818.3	21.32	4.7	3 1958
11	4191818.	2.61	2893.0	23.52	4.3	6 1949
12	4601932.	2.87	3176.0	25.72	3.9	5 1953
13	4695873.	2.93	3240.9	27.92	3.6	3 1947
14	4722014.	2.94	3258.9	30.12	3.3	8 1971
15	4832195.	3.01	3335.0	32.31	3.1	3 1969
16	5904460.	3.68	4075.0	34.51	2.9	8 1973
17	6533144.	4.07	4508.9	36.71	2.7	3 1945
18	7449727.	4.64	5141.5	38.91	2.6	8 1976
19	8516819.	5.31	5877.9	41.11	2.4	3 1967

INDEPENDENT EVENTS EXHAUSTED

(continued)

YEARS (RECORD) MONTHS   DURATION IN MONTHS
47   0   48

EFFECTIVE YEARS   DRAINAGE AREA (SQ MI)
43.08   30100.00

NUMBER	VOLUME AC-FT	DEPTH INCHES	RATE CFS	EXCEED FREQ	RECUR INT	ENDING DATE
1	1190073.	0.74	410.7	1.60	62.7	2 1935
2	1950591.	1.22	673.1	3.90	25.7	5 1940
3	4907963.	3.06	1693.6	6.20	16.1	3 1962
4	7137840.	4.45	2463.1	8.50	11.8	8 1957
5	7656444.	4.77	2642.1	10.80	9.3	5 1944
6	9797813.	6.10	3381.0	13.10	7.6	3 1950
7	10492043.	6.54	3620.6	15.40	6.5	7 1971
8	11892878.	7.41	4104.0	17.70	5.7	9 1966
9	16031991.	9.99	5532.3	20.00	5.0	9 1976

INDEPENDENT EVENTS EXHAUSTED

YEARS (RECORD) MONTHS   DURATION IN MONTHS
47   0   96

EFFECTIVE YEARS   DRAINAGE AREA (SQ MI)
39.08   30100.00

NUMBER	VOLUME AC-FT	DEPTH INCHES	RATE CFS	EXCEED FREQ	RECUR INT	ENDING DATE
1	3036641.	1.89	523.9	1.76	56.9	4 1938
2	12252640.	7.63	2114.1	4.29	23.3	3 1962
3	14620470.	9.11	2522.6	6.82	14.7	5 1946
4	23755024.	14.80	4098.7	9.36	10.7	7 1971

INDEPENDENT EVENTS EXHAUSTED

ATTACHMENT C

LIST OF ABBREVIATIONS

mgd - million gallons per day = 1.547 cfs

cfs - cubic feet per second = 0.646 mgd

mg/l - milligrams per liter

ac-ft - acre feet

gpm - gallons per minute

ATTACHMENT C

APPLICATION OF LFFØ1,C
LOW-FLOW FREQUENCY ANALYSIS

The computer program LFFØ1,C was written to check the results of the HEC program 723-G1-L2290 entitled "Partial Duration-Independent Low Flow Events." LFFØ1,C includes several modifications to the 723-G1-L2290 program. These are:

1. Direct calculation discharge-frequency relationship for the 1-month duration flows.
2. Computation of recurrence intervals down to 1 year or the total number of independent low-flow durations if the number is less than the number of years of data.

The 723-G1-L2290 program does not consider the 1-month duration. It is recommended that the program be modified by adding a subroutine to sort the monthly input data and apply the Beard's plotting positions.

The 723-G1-L2290 program ceases its printout when the recurrence interval becomes less than 2 years. This is entirely adequate for most studies since the main area of concern lies in the 20-year to 50-year range of recurrence intervals. It was found that lack of information in the 1-year to 2-year range hindered the understanding of flow characteristics in the Grand Forks-East Grand Forks area. The low-flow augmentation effects became significant for intervals of 4 years and greater (3-month duration). The low-flow augmentation flattens the low end of the discharge-frequency-duration curve. These curves generally are of single curvature, but computation of the 1-year to 2-year discharges

and frequencies indicates that the curves should be "S" shape because of the low-flow augmentation experienced. It is recommended that the printout of program 723-G1-L2290 be extended to include recurrence intervals down to 1 year or the total number of independent flow durations if this number is less than the number of years of data.

A listing of the LFF01,C program follows this discussion. The program is written in Basic and requires about 10K of R.A.M. for operation.

PROGRAM LISTING LFF01,C, LOW-FLOW FREQUENCY ANALYSIS

```
10 PRINT ;TAB(24);"Program LFF01"
20 PRINT ;TAB(18);"Low Flow Frequency Analysis"
30 PRINT : PRINT "Version Dated Aug. 1979": PRINT : PRINT
40 IF F9>0 THEN  SET OP=0: GOTO 80
50 DIM M(601),S(600),L(600)
60 INPUT "DO YOU REQUIRE RESULTS ON PRINTER ? ",F9
70 IF F9>0 THEN  SET OP=2: GOTO 10
80 INPUT "WILL YOU READ DATA FROM TAPE ? ",F7
90 IF F7>0 THEN  LET Y=1: GOTO 270
100 PRINT : PRINT "NOW ENTER MONTHLY RAW DATA IN SEQUENCE"
105 INPUT "CORRECTION TO BE ADDED TO RAW DATA INPUT (cfs) = ",G
110 INPUT "No. OF YEARS DATA TO BE ENTERED = ",N
120 LET Z=12*N+1: LET M(1)=2
125 PRINT : PRINT "NOW ENTER RAW DATA SEQUENTIALLY"
130 FOR I=2 TO Z
140 INPUT ,"   ",X: LET M(I)=X+G: NEXT I
160 PRINT : INPUT "WILL YOU STORE CORRECTED DATA ON TAPE ? ",F8
170 LET Y=1: IF F8=0 THEN 250
180 FILE #1;"LFFA",2,M(Y)
190 FOR Y=1 TO Z
200   PRINT #1;M(Y)
210 NEXT Y
220 CLOSE #1
230 PRINT "DATA TRANSFERRED TO CASSETTE TAPE"
240 PRINT "MAKE A PENCIL NOTE OF THE LOCATION OF THIS DATA"
245 PRINT "AND THE No. OF YEARS DATA STORED"
250 INPUT " WILL YOU READ DATA FROM TAPE ? ",F7
260 LET Y=1: IF F7=0 THEN 340
270 INPUT "No.OF YEARS DATA ON THIS TAPE = ",N
275 LET Z=12*N+1: FILE #1;"LFFA",1
280 FOR Y=1 TO Z
290   READ #1;M(Y)
300 NEXT Y
310 CLOSE #1: PRINT "DATA TRANSFERRED TO COMPUTER STORAGE"
340 PRINT : PRINT "LOW FLOW FREQUENCY ANALYSIS FOLLOWS ": PRINT
350 INPUT "DURATION OF LOW FLOW TO BE ANALYZED (months) = ",D
360 IF F9=0 THEN 380
370 SET OP=2: PRINT : PRINT %3I;"LOW FLOW PERIOD (months) = ";D: SET OP=0
```

"N" must be an integer.

Input Value "G" to be added to all raw data.

Values of M(Y) = corrected raw data.

(Data stored from 2 because first tape storage is reserved).

D must be an integer.

(Continued)

```
372 LET S(1)=0
375 FOR Y=2 TO D+1
380   LET S(1)=S(1)+H(Y)
390 NEXT Y
400 FOR Y=2 TO Z-D
410   LET S(Y)=S(Y-1)-H(Y)+H(Y+D)
420 NEXT Y
430 PRINT "RUNNING TOTALS NOW COMPLETED"
440 IF F9>0 THEN  SET OP=2
450 PRINT "  N      T    % P   Q (cfs)   I": SET OP=0
460 LET N=1: LET Z=Z-D
470 LET T=(N-D/12+2)/N: LET P=100/T
480 LET I=1
482 LET L=S(I): IF L>0 THEN 490
484 LET I=I+1: IF I>Z THEN  LET N=N-1: GOTO 620
486 GOTO 482
490 FOR Y=I TO Z
495   IF S(Y)<0 THEN 510
500   IF S(Y)<L THEN  LET L=S(Y): LET I=Y
510 NEXT Y
515 IF L<=0 THEN  LET N=N-1: GOTO 620
520 LET Q=L/D: LET L(N)=Q: IF F9>0 THEN  SET OP=2
530 PRINT %3I;N;%7F2;T;P;%C10F2;Q;%4I;I: SET OP=0
550 LET Z1=I-D+1: LET Z2=I+D-1
560 IF Z1<2 THEN  LET Z1=1
565 IF Z2>Z THEN  LET Z2=Z
570 FOR Y=Z1 TO Z2
580 LET S(Y)=-10: NEXT Y
590 LET N=N+1: IF N>H THEN  LET N=H: GOTO 620
595 GOTO 470
620 LET A=0: LET B=0
630 FOR Y=1 TO N
640   LET C=L(Y): LET A=A+C: LET B=B+C*C
650 NEXT Y
660 LET M1=A/N: LET S1=SQR((B-N*M1*M1)/(N+1))
670 IF F9>0 THEN  SET OP=2
680 PRINT "MEAN OF LOW FLOW VALUES = ";%C10F1;M1
690 PRINT "STD. DEVIATION OF LOW FLOWS = ";%C10F3;S1
700 PRINT : PRINT : SET OP=0: LET Z=12*N+1: GOTO 250
```

Lowest running totals selected in succession.✦ (lines 490–510)

"Overlapping" of running totals prevented. (lines 550–570)

✦ <u>Note</u>: Data is examined as Partial Duration Data (except) that "overlapping" is prevented.

Main program complete.

Some refinements follow.

(continued)

To remove the first X years from the record stored on tape

RUN 1000

```
1000 INPUT "HOW MANY YEARS WILL YOU DELETE FROM THE RECORD ?",X
1010 LET B=12*(N-X)+1: LET N=N-X
1020 FOR Y=2 TO B
1030   LET M(Y)=M(Y+12*X)
1040 NEXT Y
1045 IF F3<>0 THEN SET DP=2
1050 PRINT %3I;"FIRST";X;" YEARS DELETED FROM RECORD"
1060 SET DP=[illegible]: GOTO 300
```

To obtain a print-out of corrected monthly data used in the analysis

RUN 1100

```
1100 SET DP=[illegible]
1110 PRINT ;TAB(23);"CORRECTED RAW DATA"
1120 PRINT ;TAB(20);"For ";%3I;N;" years of record"
1130 FOR Y=2 TO 12*N+1
1140   PRINT %10F2;M(Y);
1150 NEXT Y
1160 SET DP=[illegible]: GOTO 300
```

Program and data computer storage requirement = 16 K. (14 K actually)

ATTACHMENT D

APPLICATION OF PROGRAM SDF01,C
STORAGE DEPLETION-FREQUENCY ANALYSIS

Program SDF01,C is written for Storage Depletion-Frequency Analysis of the record period by the mass curve method. The method is described in Book 4, Chapter B2, Techniques of Water-Resource Investigations of the United States Geological Survey, "Storage Analysis for Water Supply" by H. Riggs and C. Hardison, 1973 where use of daily rather than monthly discharges is recommended. Daily, rather than monthly flows would also be desirable for Frequency-Mass Curve Analysis, but in each case this would considerably increase computer effort. It must be understood that both methods will be biased to give slightly low estimates of storage requirements when monthly data are used. For some unexplained reason, Riggs and Hardison limit draft rates to the lowest year of record. This requirement does not appear to be necessary. On the contrary, the method appears to be better adapted to draft rates requiring 1-year storage than Frequency-Mass Curve Analysis.

V. Klemeš in a paper entitled "Storage-Mass-Curve Analysis in a Systems-Analytic Perspective," Water Resources Research Vol. 15, April 1979, Number 2, has done much to show that the Rippl method is not confined to analysis of the drought of record only but may be extended to Storage Deficiency-Frequency Analysis of both historical and synthetic records. He provides an example of a mass diagram with over-year storage.

The simple routing equation employed in Program SDF01,C may be written:

$$D(Y) = D(Y-1) + (Q(Y) - M(Y))*C(Y)$$

and if $D(Y) < 0$ then $D(Y) = 0$

where:

D(Y) = Reservoir storage deficiency below spillway level at the end of Month Y - - - (acre-feet)

D(Y-1) = Reservoir storage deficiency at the end of the previous month

Q(Y) = Average gross demand rate for month (Y) in cfs

M(Y) = Average inflow to the reservoir during month Y in cfs

C(Y) = Is a constant for any given calendar month to convert net average outflow to drain on reservoir storage in acre feet.

Routing begins with a storage depletion equal to the average depletion for the particular draft rate derived from a previous trial run. For the purpose of preliminary analysis for Grand Forks Q(Y) has been assumed constant throughout the year and to have a value of 38 cfs. Of this amount, 8 cfs is for downstream release and the remainder for water supply. Evaporation losses are assumed included in the inflow rate. For preliminary analysis, each month has been assumed to be of 30.42 days duration resulting in a value of 60.33 for C(Y).

A listing of Program SDF01,C in this preliminary form and written in Basic is provided at the end of this attachment. Refinement of this program to provide for varying water supply demand and the actual number of days in each month of the year would be a very simple matter. This program requires about 10K of computer capacity in addition to Basic for the analysis of up to 50 years of monthly data.

Input to the program consists of the identical tabulation of peak storage demands throughout the period of record with frequency estimates based upon the Weibull equation T = (N+1)/M.

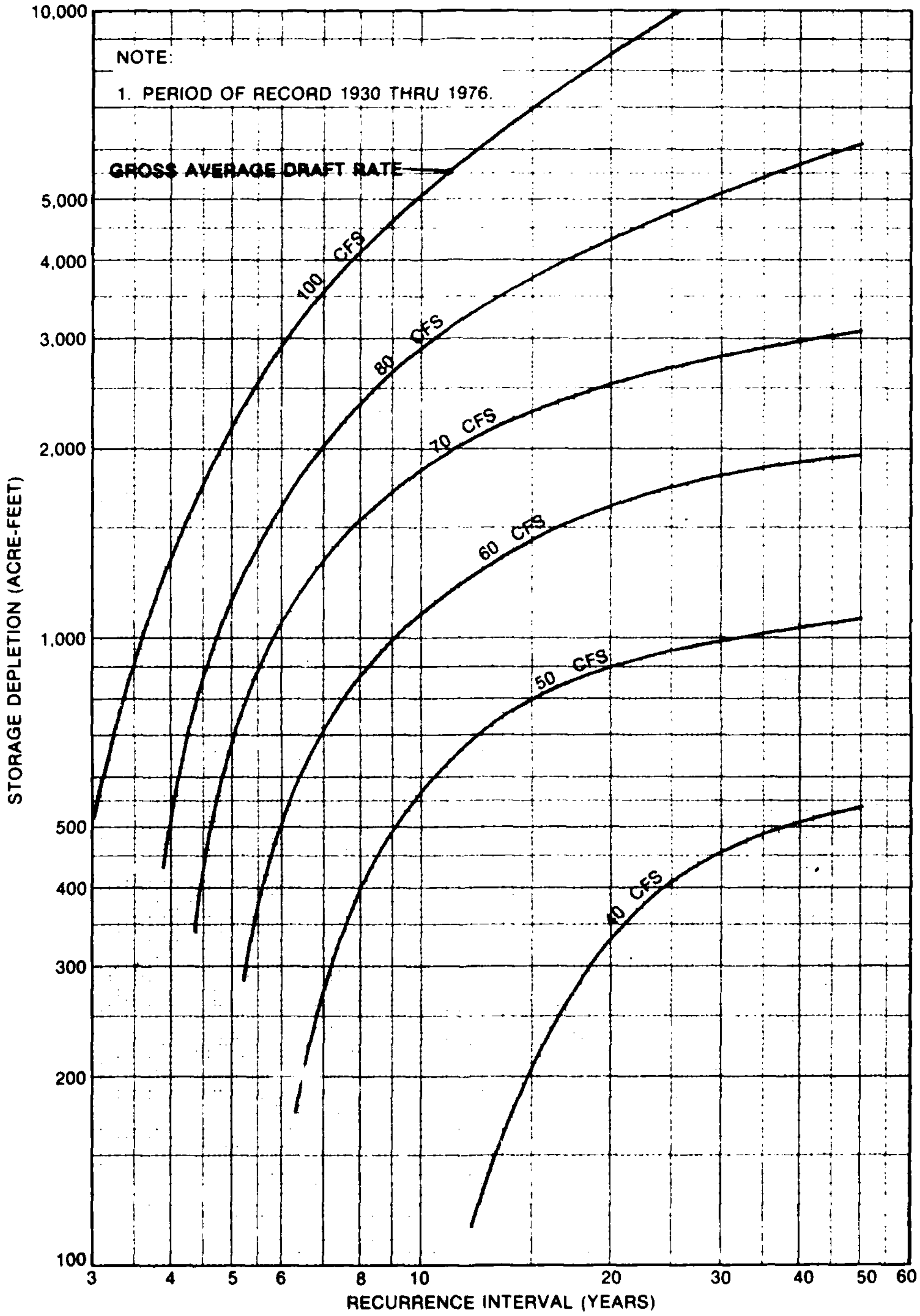
Advantages presently seen for this type of analysis are ability to provide for seasonal differences in water demand with accuracy, capability of including different loss rates for various storage values, use of actual mass curve data rather than a hypothetical design mass curve to evaluate actual storage depletion under conditions modeled to duplicate prototype behavior, and elimination of uncertainty regarding the necessity for applying corrections when the reservoir fails to overflow in any given year.

Storage depletion curves plotted using Weibull plotting positions ($T = \frac{N+1}{M}$) indicate a larger storage requirement than those plotted using the Beard median value equation commonly employed by the Corps of Engineers. For the sake of conservatism in design, we have employed Weibull plotting positions in program SDF01,C.

Results obtained for the Red River of the North at Grand Forks are presented in figure D-1. All curves plot well except for the gross demand rate of 40 cfs which amounts to only 1.3 percent of average streamflow at this location. An additional plot of storage requirement versus gross average draft rate indicated a storage requirement of about 500 acre-feet (ac-ft) to provide a total supply of 38 cfs with a 2-percent probability of failure in any given year.

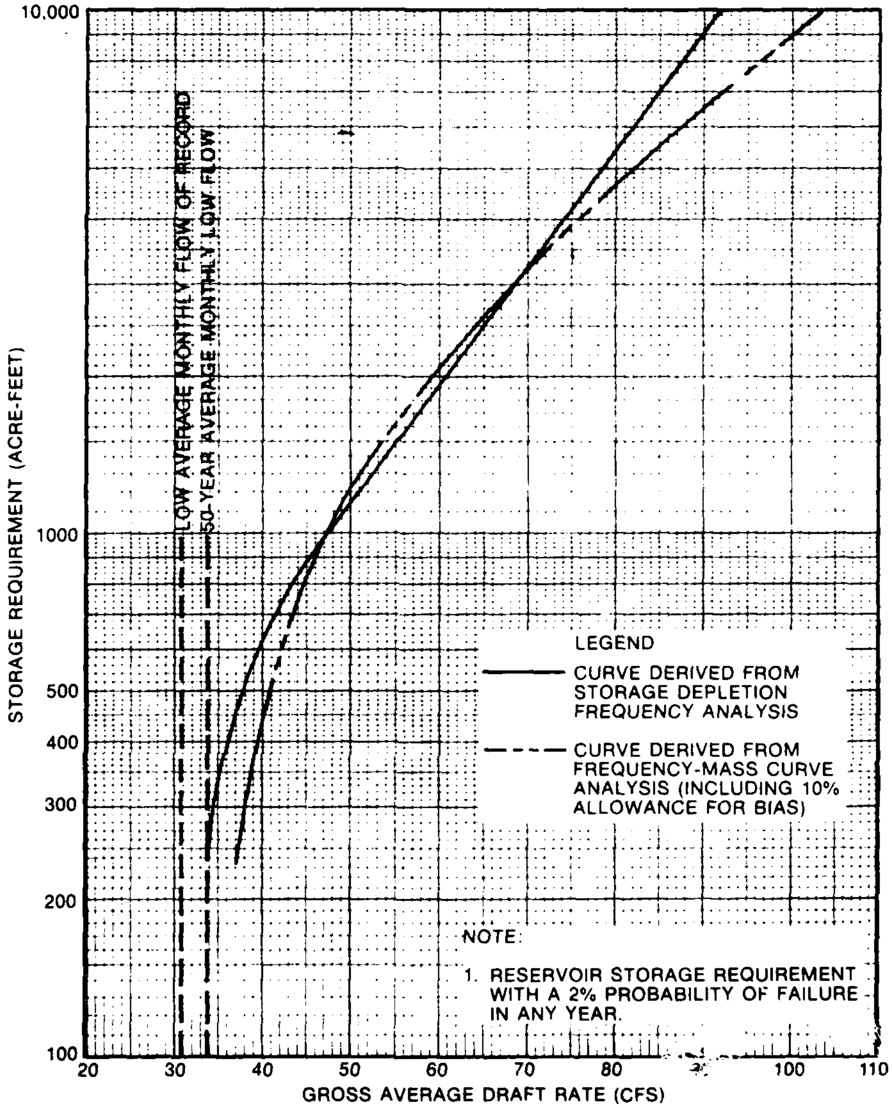
Figure D-2 shows gross draft storage relationships derived from both methods described in this report. Storage requirement to maintain a 38-cfs total supply is computed to be 265 ac-ft by low-flow frequency analysis and 500 ac-ft by Storage Depletion-Frequency Analysis. Agreement between the two methods is considered to be quite close throughout the range from 40 to 80 cfs with some divergence which illustrates the desirability of performing both forms of analysis at each end of the diagram.

The storage requirements indicated from these two analyses are presently available as in-channel storage behind the dam at Grand Forks. Therefore, further refinement of the storage requirement for water supply appears unnecessary.



Storage Depletion - Frequency
Red River of the North
at
Grand Forks, N.D.

Figure D-1



Gross Average Draft Rate
vs
Reservoir Storage Requirement
for
Red River of the North
at
Grand Forks, N.D.

Figure D-2

PROGRAM LISTING
SDFO1,C, STORAGE DEPLETION-FREQUENCY ANALYSIS

```
10 PRINT ;TAB(24);"Program SDF01"
20 PRINT ;TAB(14);"STORAGE-DEPLETION-FREQUENCY ANALYSYS"
30 PRINT : PRINT "Version Dated Aug. 1979": PRINT : PRINT
40 IF F9>0 THEN  SET OP=0: GOTO 60
50 DIM M(601),D(601)
60 INPUT "DO YOU REQUIRE RESULTS ON PRINTER ? ",F9
70 IF F9>0 THEN  SET OP=2: GOTO 10
80 INPUT "WILL YOU READ DATA FROM TAPE ? ",F7
90 IF F7>0 THEN  LET Y=1: GOTO 270
100 PRINT : PRINT "NOW ENTER MONTHLY RAW DATA IN SEQUENCE"
105 INPUT "CORRECTION TO BE ADDED TO RAW DATA INPUT (cfs) = ",G
110 INPUT "No. OF YEARS DATA TO BE ENTERED = ",N
120 LET Z=12*N+1: LET M(1)=2
125 PRINT : PRINT "NOW ENTER RAW DATA SEQUENTIALLY"
130 FOR I=2 TO Z
140 INPUT ," ",X: LET M(I)=X+G: NEXT I
160 PRINT : INPUT "WILL YOU STORE CORRECTED DATA ON TAPE ? ",F8
170 LET Y=1: IF F8=0 THEN 250
180 FILE #1;"LFFA",2,M(Y)
190 FOR Y=1 TO Z
200   PRINT #1;M(Y)
210 NEXT Y
220 CLOSE #1
230 PRINT "DATA TRANSFERRED TO CASSETTE TAPE"
240 PRINT "MAKE A PENCIL NOTE OF THE LOCATION OF THIS DATA"
245 PRINT "AND THE No. OF YEARS DATA STORED"
250 INPUT " WILL YOU READ DATA FROM TAPE ? ",F7
260 LET Y=1: IF F7=0 THEN 340
270 INPUT "No.OF YEARS DATA ON THIS TAPE = ",N
275 LET Z=12*N+1: FILE #1;"LFFA",1
280 FOR Y=1 TO Z
290   READ #1;M(Y)
300 NEXT Y
310 CLOSE #1: PRINT "DATA TRANSFERRED TO COMPUTER STORAGE"
340 PRINT : PRINT "STORAGE DEPLETION FREQUENCY ANALYSIS FOLLOWS ": PRINT
350 INPUT "GROSS AVERAGE DEMAND (cfs) = ",Q
360 INPUT "INITIAL STORAGE DEPLETION (A-ft) = ",D(1)
365 IF F9>0 THEN  SET OP=2
370 PRINT ;TAB(5);"GROSS AVERAGE DEMAND = ";Q;" (cfs)"
```

NOTE: This is a preliminary version of a program intended for further development to provide for seasonal variation in water demands and evaporation losses, etc.

INPUT
DATA
FROM
KEYBOARD
OR
CASSETTE TAPE
STORAGE

(Monthly data is filed so as to be usable in program LFF01,C also)

(continued)

```
380 PRINT %10F1;"INITIAL STORAGE DEPLETION = ";D(1);" A-FT.": SET OP=0
390 FOR Y=2 TO Z
400   LET D(Y)=D(Y-1)+(Q-M(Y))*60.33
410   IF D(Y)<0 THEN  LET D(Y)=0
420 NEXT Y
430 LET S=0
440 FOR Y=2 TO Z
450   LET S=S+D(Y)
460 NEXT Y
470 LET S=S/(Z-1): LET Y=2
480 IF D(Y)=0 THEN 500
490 LET D(Y)=0: LET Y=Y+1: IF D(Y)>0 THEN 490
500 LET Y=Z
510 IF D(Y)=0 THEN 530
520 LET D(Y)=0: LET Y=Y-1: IF D(Y)>0 THEN 520
530 LET Y=2: LET M=1
540 IF D(Y)=0 THEN  LET Y=Y+1: GOTO 540
550 LET T1=Y: LET N1=N-(T1-1)/12
560 LET Y=Z
570 IF F9>0 THEN  SET OP=2
580 PRINT %7F1;"ESTIMATED AVERAGE STORAGE DEPLETION = ";S;" A-ft"
590 PRINT %7F2;"REPRESENTATIVE RECORD PERIOD = ";N1;" YEARS"
600 PRINT : PRINT "  M      I      J      T    % P Acre-feet"
610 SET OP=0: LET T=(N1+1)/M: LET P=100/T
620 LET L=0
630 FOR Y=2 TO Z
640   IF D(Y)>L THEN  LET L=D(Y): LET I=Y
650 NEXT Y
660 IF L=0 THEN 800
670 LET Y=I: LET J=1
680 IF D(Y-1)>0 THEN  LET J=J+1: LET Y=Y-1: GOTO 680
690 IF D(Y)>0 THEN  LET D(Y)=0: LET Y=Y+1: GOTO 690
695 IF F9>0 THEN  SET OP=2
700 PRINT %3I;M;%7I;I-1;J;%7F2;T;P;%C10F1;L
710 SET OP=0: LET M=M+1: IF M>N1 THEN 800
720 GOTO 610
800 SET OP=2: PRINT : PRINT : SET OP=0: GOTO 340
850 SET OP=2: PRINT : PRINT
```

FUNDEMENTAL ROUTING EQUATIONS

S = average depletion during record period

eliminate incomplete drawdown periods from record.

Find start of first complete drawdown period

Lessen total record period by this amount.

Weibull plotting position

Find max. depletion in period from T1 to 2.

Delete from record to find next highest peak drawdown.

(continued)

```
860 PRINT "LISTING OF CORRECTED MONTHLY INPUT DATA"
870 FOR Y=2 TO Z
880   PRINT %C10F1;M(Y);
890 NEXT Y
900 SET OP=0: STOP
960 SET OP=0
965 FOR Y=2 TO Z
970   PRINT %C10F1;D(Y);
980 NEXT Y
[illegible]
```

ATTACHMENT E

LOW-FLOW FREQUENCY DETERMINATION BY DROUGHT CULMINATION-FREQUENCY ANALYSIS

Computer programs such as HEC's "Partial Duration - Independent Low-Flow Events" and LFF01 described in this report derive a series of "nonoverlapping" worst droughts of various durations throughout the period of record. Because more than one nonoverlapping drought might be extracted from any one year, a partial duration series is used. For droughts of duration less than 1 year, results obtained from such computer programs appear realistic and have been successfully applied to reservoir design.

Computer output for durations in excess of 1 year is, however, unacceptable for immediate application to reservoir design. The procedure used within the program eliminates overlap and results in a print-out of rare "droughts" which are found to have an average discharge significantly higher than the long-term average flow of the river. (The 10.7-year, 96-month drought for the Red River of the North given in Attachment B illustrates this anomaly.) The State of Kansas adjustment procedure represents an attempt to adjust computer results for this deficiency. The method is semigraphical and is based on an idealized distribution of drought flows.

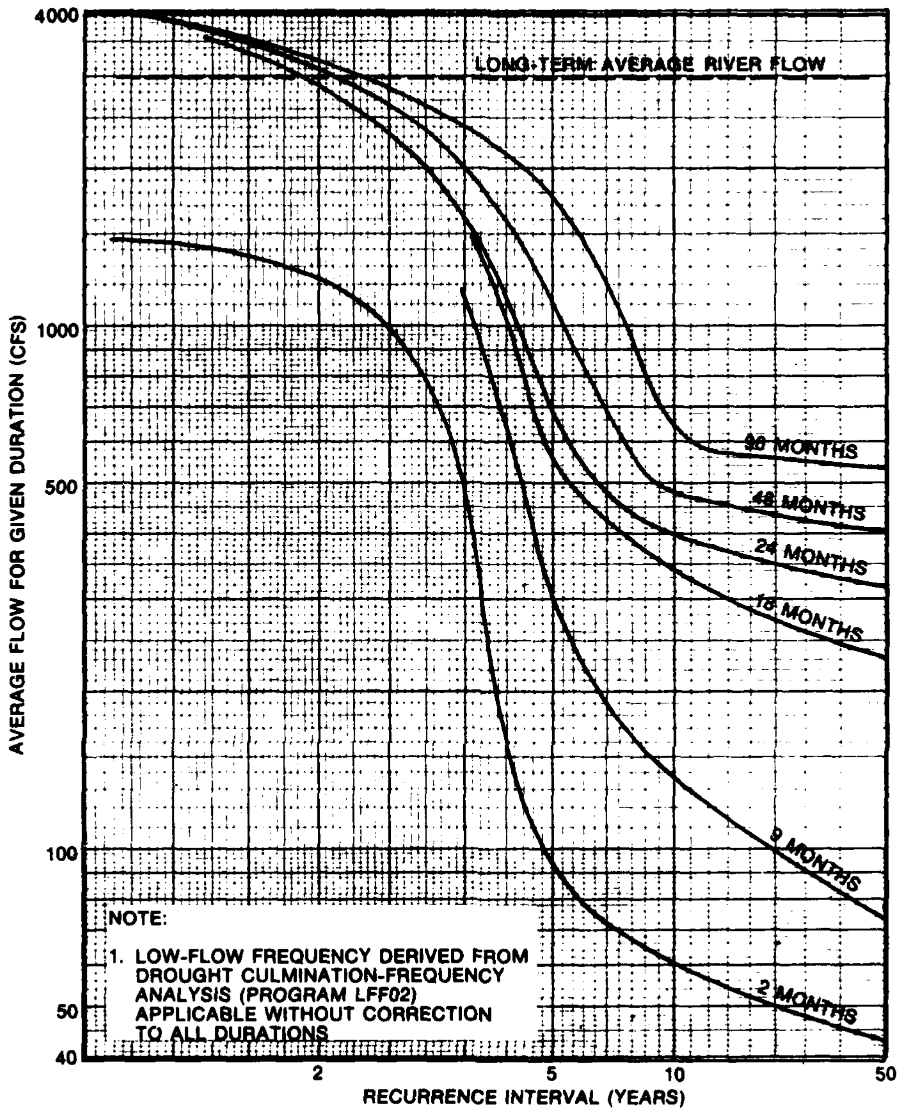
This attachment presents a method of low-flow frequency analysis which is believed to be an improvement on the existing methods and eliminates the need for subsequent corrections. It is recommended that the HEC low-flow frequency method be modified by this drought culmination-frequency analysis whenever it is selected for use in situations where long duration droughts may prove critical.

The concept of drought culmination-frequency is derived from recognizing the probability of a drought of any duration ending in any water year. As the drought ends, reservoir drawdown will be at a maximum. Reservoirs are designed to provide sufficient storage so that, for a given drought recurrence interval, storage will be sufficient to provide the required supply no matter what drawdown condition results in the reservoir before the drought "breaks." Conditions at the ends of droughts are critical for reservoir design.

Consequently, analysis of the statistic of the worst drought of given duration which might end in a given water year exactly duplicates the design problem. Since, for any duration, only one "worst drought" is experienced in a given year, the series being examined is of annual maxima. Overlapping of raw data is permissible since the statistic being sought is concerned only with results at the end of each drought period.

Computer program LFF02,C "Drought Culmination-Frequency Analysis," was developed and represents a simple modification of program LFF01 to evaluate this required statistic. A complete listing of LFF02, written in basic, follows this discussion. This program illustrates how other low-flow-frequency programs might be amended to incorporate the essential principle.

Also included are representative analyses for Red River of the North at Grand Forks, North Dakota, together with a plot of results obtained from application of program LFF02(Figure E-1). It is immediately apparent that the requirement of the state of Kansas adjustment procedure that 2-year droughts for duration in excess of 12 months approximate average long-term river flow is automatically provided by this program. Results for durations less than 1 year agree closely with those obtained from standard low-flow-frequency programs. Agreement with similar results using the State of Kansas adjustment procedure is not so satisfactory. Since the statistic employed in program LFF02 is simple to understand and models the requirement for reservoir design, and since



Low-Flow Frequency
Red River of the North
at
Grand Forks, N.D.

Figure E-1

by allowing plotting of smooth curves through the computed low-flow-frequency results, no requirement for any distribution of drought flows is demanded. It is believed that results from program LFF02 will be more reliable than those obtained using the State of Kansas adjustment procedure.

The approach presented in this attachment could be included in the HEC program, "Partial Duration-Independent Low-Flow Events."

```
10 PRINT ;TAB(24);"Program LFF02"
20 PRINT ;TAB(19);"Drought Culmination Frequency"
30 PRINT : PRINT "Version Dated Aug. 1979"
40 IF F9>0 THEN  SET OP=0: GOTO 80
50 DIM M(601),S(600),T(12)
60 INPUT "DO YOU REQUIRE RESULTS ON PRINTER ? ",F9
70 IF F9>0 THEN  SET OP=2: GOTO 10
80 INPUT "WILL YOU READ DATA FROM TAPE ? ",F7
90 IF F7>0 THEN  LET Y=1: GOTO 270
100 PRINT : PRINT "NOW ENTER MONTHLY RAW DATA IN SEQUENCE"
105 INPUT "CORRECTION TO BE ADDED TO RAW DATA INPUT (cfs) = ",G
110 INPUT "No. OF YEARS DATA TO BE ENTERED = ",N
120 LET Z=12*N+1: LET M(1)=2
125 PRINT : PRINT "NOW ENTER RAW DATA SEQUENTIALLY"
130 FOR I=2 TO Z
140 INPUT ,"  ",X: LET M(I)=X+G: NEXT I
160 PRINT : INPUT "WILL YOU STORE CORRECTED DATA ON TAPE ? ",F8
170 LET Y=1: IF F8=0 THEN 250
180 FILE #1;"LFFA",2,M(Y)
190 FOR Y=1 TO Z
200   PRINT #1;M(Y)
210 NEXT Y
220 CLOSE #1
230 PRINT "DATA TRANSFERRED TO CASSETTE TAPE"
240 PRINT "MAKE A PENCIL NOTE OF THE LOCATION OF THIS DATA"
245 PRINT "AND THE No. OF YEARS DATA STORED"
250 INPUT " WILL YOU READ DATA FROM TAPE ? ",F7
260 LET Y=1: IF F7=0 THEN 340
270 INPUT "No.OF YEARS DATA ON THIS TAPE = ",N
275 LET Z=12*N+1: FILE #1;"LFFA",1
280 FOR Y=1 TO Z
290   READ #1;M(Y)
300 NEXT Y
310 CLOSE #1: PRINT "DATA TRANSFERRED TO COMPUTER STORAGE"
340 PRINT "DROUGHT CULMINATION FREQUENCY ANALYSIS FOLLOWS ": PRINT
350 LET I=1
360 LET A=I+1: LET T(I)=0
370 LET T(I)=T(I)+M(A): LET C=C+1
```

PROGRAM LISTING
LFF02,C, DROUGHT CULMINATION-FREQUENCY ANALYSIS

Written in Extended Basic for Processor Technology SOL20 Computer

Dimensioned for 50 years of data - could accept much more.

HEC-3 print-out requires "adding back" of water allowed for water supply.

(continued)

```
380 LET A=A+12: IF A<=Z THEN 370
390 LET T(I)=T(I)/N: LET I=I+1: IF I<13 THEN 360
400 IF F9>0 THEN  SET OP=2
410 PRINT : PRINT "AVERAGE FLOWS FOR EACH MONTH FOLLOW"
420 FOR I=1 TO 12
430   PRINT %10F2;T(I);
440 NEXT I
450 PRINT : PRINT : SET OP=0
460 INPUT "WATER YEAR BEGINS IN MONTH No. ",A
470 IF F9>0 THEN  SET OP=2
480 PRINT %3I;"FOR WATER YEAR BEGINNING IN MONTH No. ";A: SET OP=0
490 LET A=A+1
500 INPUT "ENTER DROUGHT PERIOD (months) = ",P
510 LET B=A: LET C=1
520 IF B-P+1<2 THEN  LET B=B+12: GOTO 520
530 IF B>(Z-11) THEN  PRINT "DROUGHT PERIOD TOO LONG": GOTO 500
540 LET G=B: LET F=G-P+1: LET S(G)=0
550 FOR I=F TO G
560   LET S(G)=S(G)+M(I)
570 NEXT I
580 LET G=G+1: IF G>Z THEN 595
590 LET S(G)=S(G-1)-M(F)+M(G): LET F=F+1: GOTO 580
595 PRINT "RUNNING TOTALS COMPLETE,FINDING ANNUAL DROUGHTS"
600 LET G=B-1
610 LET F=G+1: LET G=F+11: LET X=99999999
620 FOR I=F TO G
630   IF S(I)<X THEN  LET X=S(I)
640 NEXT I
650 LET S(F)=X: IF G+12<=Z THEN 610
660 IF F9>0 THEN  SET OP=2
670 PRINT %4I;"FOR A DROUGHT PERIOD OF ";P;" (months)"
680 PRINT "   M       T   % P   Q (cfs)   Y"
690 LET N2=(F-B)/12+1: LET M=1
700 LET T=(N2+1)/M: LET P1=100/T: LET Q=99999999
710 FOR I=B TO F STEP 12
720   IF S(I)<Q THEN  LET Q=S(I): LET Y=INT((I-2)/12)+1: LET Y2=I
730 NEXT I
740 LET Q=Q/P: LET S(Y2)=99999999
```

Input month following month of greatest average flow.

Replace value for first month of water year by <u>minimum</u> value during year.

<u>NOTE</u>: Weibull plotting positions used.

Find minimum value amongst yearly values successively replacing used value by a high number.

(continued)

```
750 PRINT %4I;M;%8F2;T;%6F1;P1;%10F2;Q;%5I;Y
760 LET M=M+1: IF M<(N2+1) THEN 700
770 PRINT : SET OP=0: GOTO 500
780 STOP : END
```

M = Order of Magnitude: T = Recurrence Interval (years)(Weibull)
P = % prob. of drought in any year: Q = mean flow during drought
Y = Calendar year when drought <u>ends</u>.

PROGRAM LFF02,C, ANALYSES RED RIVER OF THE NORTH AT GRAND FORKS

AVERAGE FLOWS FOR EACH MONTH FOLLOW
1,459.30 1,394.28 1,228.77 1,081.79 1,137.70 2,998.02 10,257.85 5,843.34
4,484.81 2,847.30 1,721.81 1,952.36

FOR WATER YEAR BEGINNING IN MONTH No. 8
FOR A DROUGHT PERIOD OF 2 (months)

M	T	% P	Q (cfs)	Y
1	47.00	2.1	46.50	10
2	23.50	4.3	48.00	7
3	15.67	6.4	52.00	4
4	11.75	8.5	58.50	5
5	9.40	10.6	59.50	3
6	7.83	12.8	71.50	1
7	6.71	14.9	77.50	11
8	5.88	17.0	79.00	8
9	5.22	19.1	81.00	9
10	4.70	21.3	85.50	6
11	4.27	23.4	94.50	2
12	3.92	25.5	345.00	19
13	3.62	27.7	395.00	30
14	3.36	29.8	408.50	31
15	3.13	31.9	686.50	35
16	2.94	34.0	787.00	27
17	2.76	36.2	863.00	12
18	2.61	38.3	870.50	29
19	2.47	40.4	917.00	21
20	2.35	42.6	1045.00	32
21	2.24	44.7	1107.50	26
22	2.14	46.8	1253.00	34
23	2.04	48.9	1272.50	14
24	1.96	51.1	1308.00	23
25	1.88	53.2	1316.00	38
26	1.81	55.3	1333.00	33
27	1.74	57.4	1340.50	45
28	1.68	59.6	1350.50	46
29	1.62	61.7	1364.50	40
30	1.57	63.8	1387.00	13
31	1.52	66.0	1399.00	25
32	1.47	68.1	1420.00	20

ETC.

NOTE:

Y denotes calendar year in which the drought period ends.

M = Order of magnitude.

T = Recurrence interval (Weibull plotting position)

P = % probability.

Q = Average flow.

(continued)

AVERAGE FLOWS FOR EACH MONTH FOLLOW

1,458.30	1,394.28	1,228.77	1,081.79	1,137.70	2,998.02
10,257.35	5,943.34	4,484.81	2,847.30	1,721.81	1,952.36

FOR WATER YEAR BEGINNING IN MONTH No. 8

FOR A DROUGHT PERIOD OF 9 (months)

M	T	% P	Q (cfs)	Y
1	46.00	2.2	71.56	7
2	23.00	4.3	101.56	5
3	15.33	6.5	118.00	10
4	11.50	8.7	135.56	4
5	9.20	10.9	146.89	3
6	7.67	13.0	171.56	11
7	6.57	15.2	207.67	2
8	5.75	17.4	242.00	9
9	5.11	19.6	250.56	6
10	4.60	21.7	430.00	8
11	4.18	23.9	704.44	30
12	3.83	26.1	873.89	19
13	3.54	28.3	913.11	31
14	3.29	30.4	1204.00	32
15	3.07	32.6	1213.11	12
16	2.88	34.8	1273.67	35
17	2.71	37.0	1356.78	27
18	2.56	39.1	1442.00	29
19	2.42	41.3	1547.00	20
20	2.30	43.5	1582.78	34
21	2.19	45.7	1613.78	25
22	2.09	47.8	1638.78	26
23	2.00	50.0	1686.33	45
24	1.92	52.2	1727.89	40
25	1.84	54.3	1738.22	38
26	1.77	56.5	1806.33	13
27	1.70	58.7	1852.22	18
28	1.64	60.9	1866.67	14
29	1.59	63.0	1866.89	41
30	1.53	65.2	1877.56	21
31	1.48	67.4	1900.22	20

Begin water year after peak month.

M = Order of magnitude.

T = Recurrence interval (Weibull = $\frac{N+1}{M}$)

P = % probability in any year.

Q = Mean discharge.

Y = Calendar year when drought ends.

(continued)

FOR A DROUGHT PERIOD OF 18 (months)

M	T	% P	Q (cfs)	Y
1	46.00	2.2	214.00	5
2	23.00	4.3	266.22	2
3	15.33	6.5	330.72	4
4	11.50	8.7	370.67	6
5	9.20	10.9	391.61	10
6	7.67	13.0	458.39	11
7	6.57	15.2	466.22	3
8	5.75	17.4	473.06	8
9	5.11	19.6	526.44	7
10	4.60	21.7	717.44	9
11	4.18	23.9	991.61	12
12	3.83	26.1	1249.83	32
13	3.54	28.3	1274.39	30
14	3.29	30.4	1458.22	31
15	3.07	32.6	1941.00	29
16	2.88	34.8	1971.61	26
17	2.71	37.0	1994.61	20
18	2.56	39.1	2071.94	27
19	2.42	41.3	2081.44	35
20	2.30	43.5	2147.89	39
21	2.19	45.7	2174.50	25
22	2.09	47.8	2187.78	34
23	2.00	50.0	2247.11	13
24	1.92	52.2	2386.72	28
25	1.84	54.3	2587.44	33
26	1.77	56.5	2682.28	24
27	1.70	58.7	2685.83	19
28	1.64	60.9	2718.17	42
29	1.59	63.0	2780.61	22
30	1.53	65.2	2785.89	17
31	1.48	67.4	2858.39	15
32	1.44	69.6	3230.22	41
33	1.39	71.7	3257.22	23
34	1.35	73.9	3462.67	16
35	1.31	76.1	3474.39	38
36	1.28	78.3	3522.00	14
37	1.24	80.4	3780.94	18
38	1.21	82.6	3935.22	36
39	1.18	84.8	3965.56	44
40	1.15	87.0	4262.83	40
41	1.12	89.1	4329.61	43
42	1.10	91.3	4833.56	37

M = Order of magnitude.

T = Recurrence interval (Weibull plotting position)

P = % probability.

Q = Mean flow.

Y = Calendar year drought ends.

(continued)

FOR A DROUGHT PERIOD OF 24 (months)

M	T	% P	Q (cfs)	Y
1	45.00	2.2	333.25	5
2	22.50	4.4	337.38	6
3	15.00	6.7	401.04	4
4	11.25	8.9	463.58	3
5	9.00	11.1	549.38	8
6	7.50	13.3	558.71	11
7	6.43	15.6	570.92	7
8	5.63	17.8	664.38	10
9	5.00	20.0	698.00	9
10	4.50	22.2	794.21	12
11	4.09	24.4	1559.75	30
12	3.75	26.7	1603.50	32
13	3.46	28.9	1671.96	31
14	3.21	31.1	1765.04	13
15	3.00	33.3	2250.67	26
16	2.81	35.6	2259.25	33
17	2.65	37.8	2345.92	29
18	2.50	40.0	2350.83	27
19	2.37	42.2	2377.17	28
20	2.25	44.4	2437.13	35
21	2.14	46.7	2771.67	25
22	2.05	48.9	2893.00	20
23	1.96	51.1	3000.33	24
24	1.88	53.3	3234.04	14
25	1.80	55.6	3240.88	17
26	1.73	57.8	3258.92	42
27	1.67	60.0	3295.17	19
28	1.61	62.2	3325.79	23
29	1.55	64.4	3339.13	39
30	1.50	66.7	3519.08	15
31	1.45	68.9	3592.63	36
32	1.41	71.1	3613.46	16
33	1.36	73.3	3674.42	18
34	1.32	75.6	3731.42	41
35	1.29	77.8	3737.88	38
36	1.25	80.0	3894.21	43
37	1.22	82.2	3964.71	40
38	1.18	84.4	4013.00	44
39	1.15	86.7	4199.13	34
40	1.13	88.9	4616.13	21
41	1.10	91.1	5389.58	22
42	1.07	93.3	5409.50	37

M = Order of magnitude.

T = Recurrence interval (Weibull plotting position)

P = % probability.

Q = Mean discharge.

Y = Calendar year when drought ends.

(continued)

FOR A DROUGHT PERIOD OF 36 (months)

M	T	% P	Q (cfs)	Y
1	44.00	2.3	374.42	6
2	22.00	4.5	375.44	5
3	14.67	6.8	452.75	4
4	11.00	9.1	488.69	7
5	8.80	11.4	532.44	8
6	7.33	13.6	664.08	11
7	6.29	15.9	693.44	10
8	5.50	18.2	721.83	9
9	4.89	20.5	757.58	12
10	4.40	22.7	1380.72	13
11	4.00	25.0	1658.28	32
12	3.67	27.3	1711.33	31
13	3.38	29.5	2058.22	30
14	3.14	31.8	2168.64	33
15	2.93	34.1	2271.69	29
16	2.75	36.4	2336.28	28
17	2.59	38.6	2350.19	27
18	2.44	40.9	2481.47	14
19	2.32	43.2	2586.06	26
20	2.20	45.5	2781.72	25
21	2.10	47.7	3197.31	15
22	2.00	50.0	3282.58	34
23	1.91	52.3	3349.14	24
24	1.83	54.5	3376.28	36
25	1.76	56.8	3464.39	17
26	1.69	59.1	3479.67	20
27	1.63	61.4	3491.78	19
28	1.57	63.6	3587.86	44
29	1.52	65.9	3703.50	18
30	1.47	68.2	3729.61	35
31	1.42	70.5	3881.56	16
32	1.38	72.7	3922.36	43
33	1.33	75.0	3926.25	41
34	1.29	77.3	3955.97	40
35	1.26	79.5	3976.97	39
36	1.22	81.8	4050.78	42
37	1.19	84.1	4444.03	21
38	1.16	86.4	4449.00	22
39	1.13	88.6	4461.33	23
40	1.10	90.9	4542.47	37
41	1.07	93.2	4643.47	38
42	1.05	95.5	5277.36	45
43	1.02	97.7	5999.06	46

(continued)

FOR A DROUGHT PERIOD OF 40 (months):

M	T	% P	Q (cfs)	Y
1	43.00	2.3	410.67	5
2	21.50	4.7	439.63	6
3	14.33	7.0	452.08	7
4	10.75	9.3	474.58	8
5	8.60	11.6	658.77	9
6	7.17	14.0	673.10	11
7	6.14	16.3	673.15	10
8	5.38	18.6	827.63	12
9	4.78	20.9	1206.63	13
10	4.30	23.3	1693.63	32
11	3.91	25.6	2008.94	31
12	3.58	27.9	2014.13	14
13	3.31	30.2	2082.33	33
14	3.07	32.6	2176.81	30
15	2.87	34.9	2349.48	29
16	2.69	37.2	2463.10	28
17	2.53	39.5	2584.90	27
18	2.39	41.9	2642.06	15
19	2.26	44.2	2732.00	26
20	2.15	46.5	2958.79	34
21	2.05	48.8	3097.98	25
22	1.95	51.2	3159.58	35
23	1.87	53.5	3381.00	20
24	1.79	55.8	3441.98	19
25	1.72	58.1	3622.65	42
26	1.65	60.5	3637.44	44
27	1.59	62.8	3663.38	16
28	1.54	65.1	3807.10	18
29	1.48	67.4	3809.23	17
30	1.43	69.8	3856.00	41
31	1.39	72.1	3895.88	36
32	1.34	74.4	3918.46	43
33	1.30	76.7	4103.96	37
34	1.26	79.1	4108.96	40
35	1.23	81.4	4194.96	24
36	1.19	83.7	4295.17	23
37	1.16	86.0	4303.06	22
38	1.13	88.4	4458.00	39
39	1.10	90.7	4473.77	21
40	1.08	93.0	4501.29	38
41	1.05	95.3	4941.44	45
42	1.02	97,7	5789.13	46

(continued)

FOR A DROUGHT PERIOD OF . % (months)

N	T	% P	Q (cfs)	Y
1	39.00	2.6	550.94	9
2	19.50	5.1	574.54	10
3	13.00	7.7	583.19	11
4	9.75	10.3	651.10	12
5	7.80	12.8	932.70	13
6	6.50	15.4	1375.27	14
7	5.57	17.9	1657.58	15
8	4.88	20.5	2114.05	32
9	4.33	23.1	2260.61	16
10	3.90	25.6	2267.41	33
11	3.55	28.2	2310.27	31
12	3.25	30.8	2454.41	30
13	3.00	33.3	2522.59	17
14	2.79	35.9	2651.01	35
15	2.60	38.5	2651.75	34
16	2.44	41.0	2723.73	29
17	2.29	43.6	2955.61	36
18	2.17	46.2	2963.96	18
19	2.05	48.7	3341.52	28
20	1.95	51.3	3435.44	37
21	1.86	53.8	3453.34	19
22	1.77	56.4	3510.94	27
23	1.70	59.0	3530.35	26
24	1.63	61.5	3540.80	20
25	1.56	64.1	3763.77	38
26	1.50	66.7	3785.88	25
27	1.44	69.2	3812.50	39
28	1.39	71.8	3946.89	24
29	1.34	74.4	3965.53	23
30	1.30	76.9	4059.64	22
31	1.26	79.5	4099.70	42
32	1.22	82.1	4107.74	41
33	1.18	84.6	4166.11	21
34	1.15	87.2	4172.52	44
35	1.11	89.7	4332.20	43
36	1.08	92.3	4357.48	40
37	1.05	94.9	4514.08	45
38	1.03	97.4	4755.78	46

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